



Jet Propulsion Laboratory
California Institute of Technology

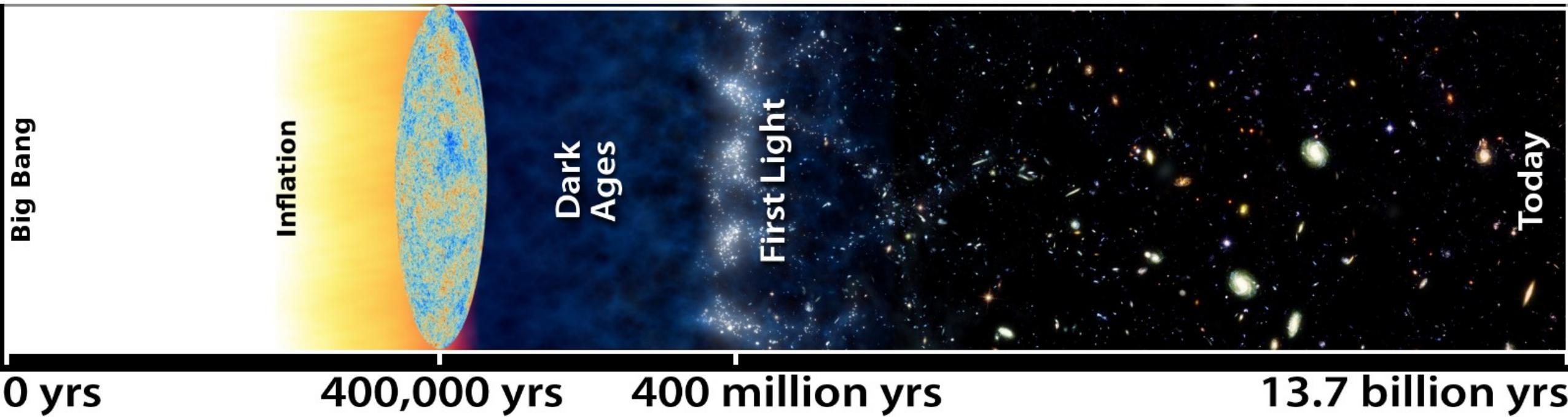
The accelerated universe through weak lensing

Agnès Ferté

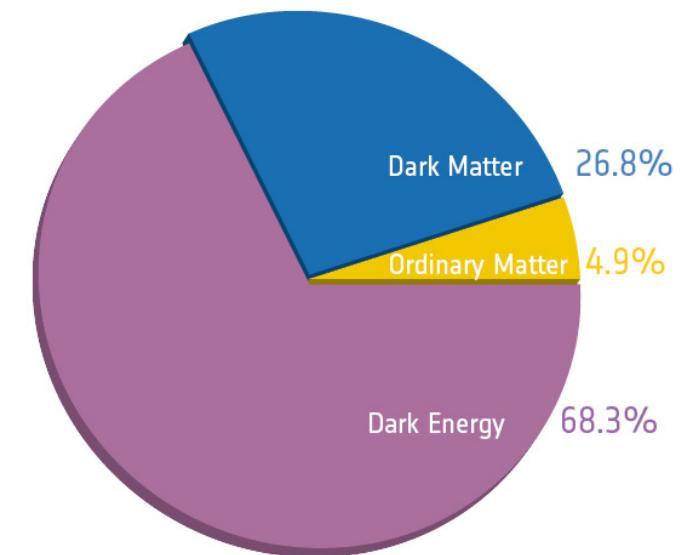
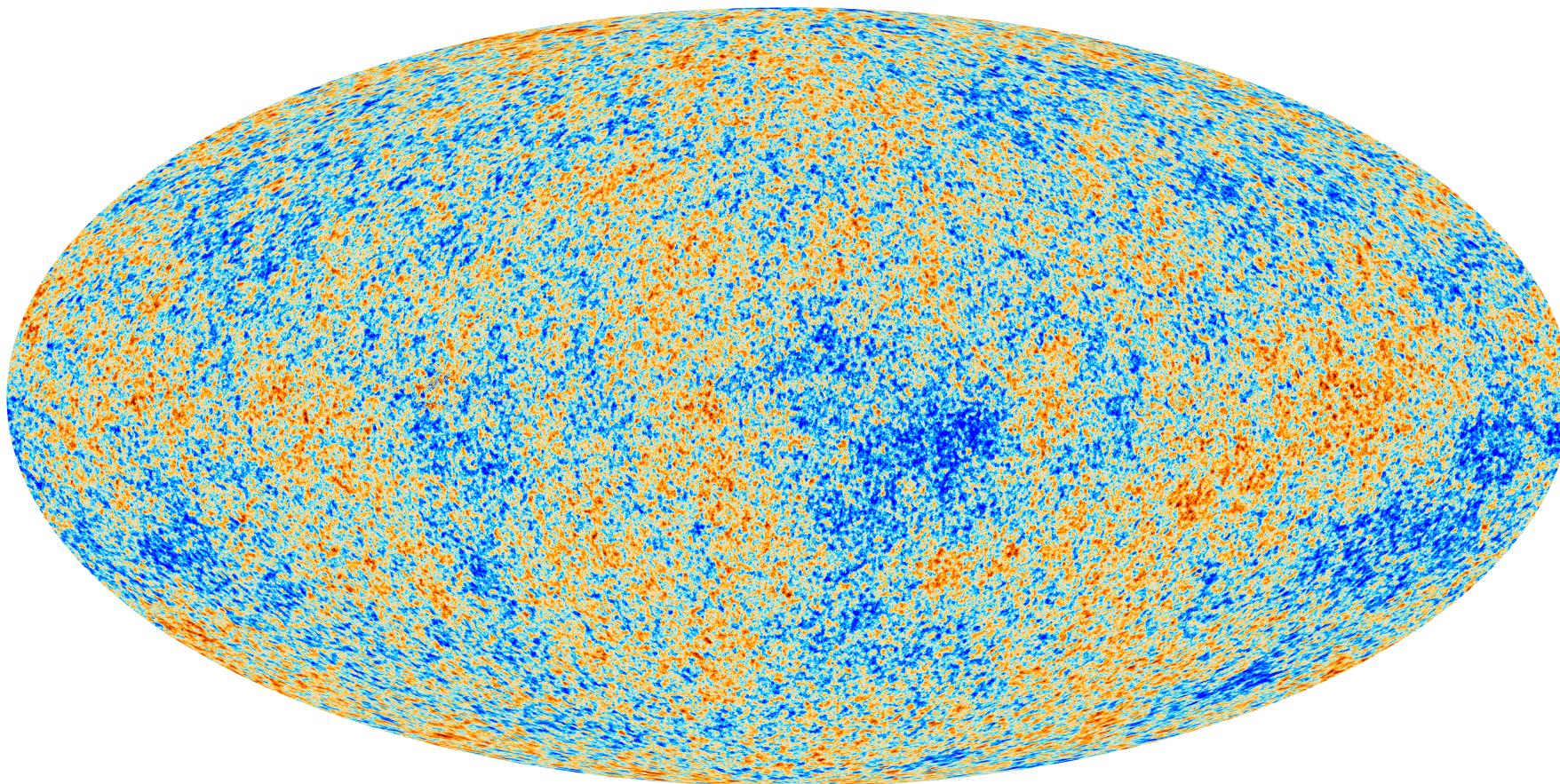
Jet Propulsion Laboratory, California Institute of Technology

The Λ CDM model

Credits: ESO

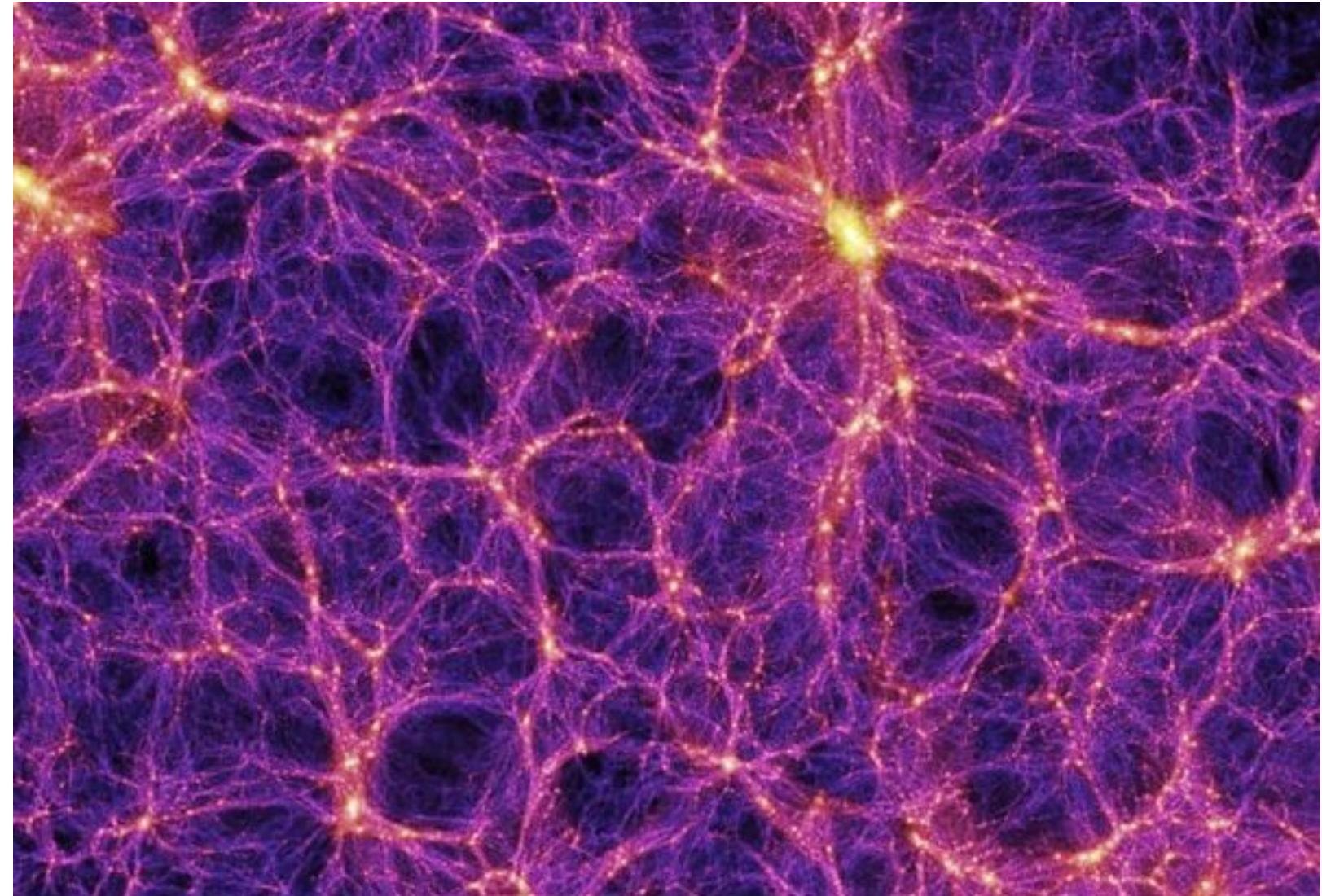


The Cosmic microwave background

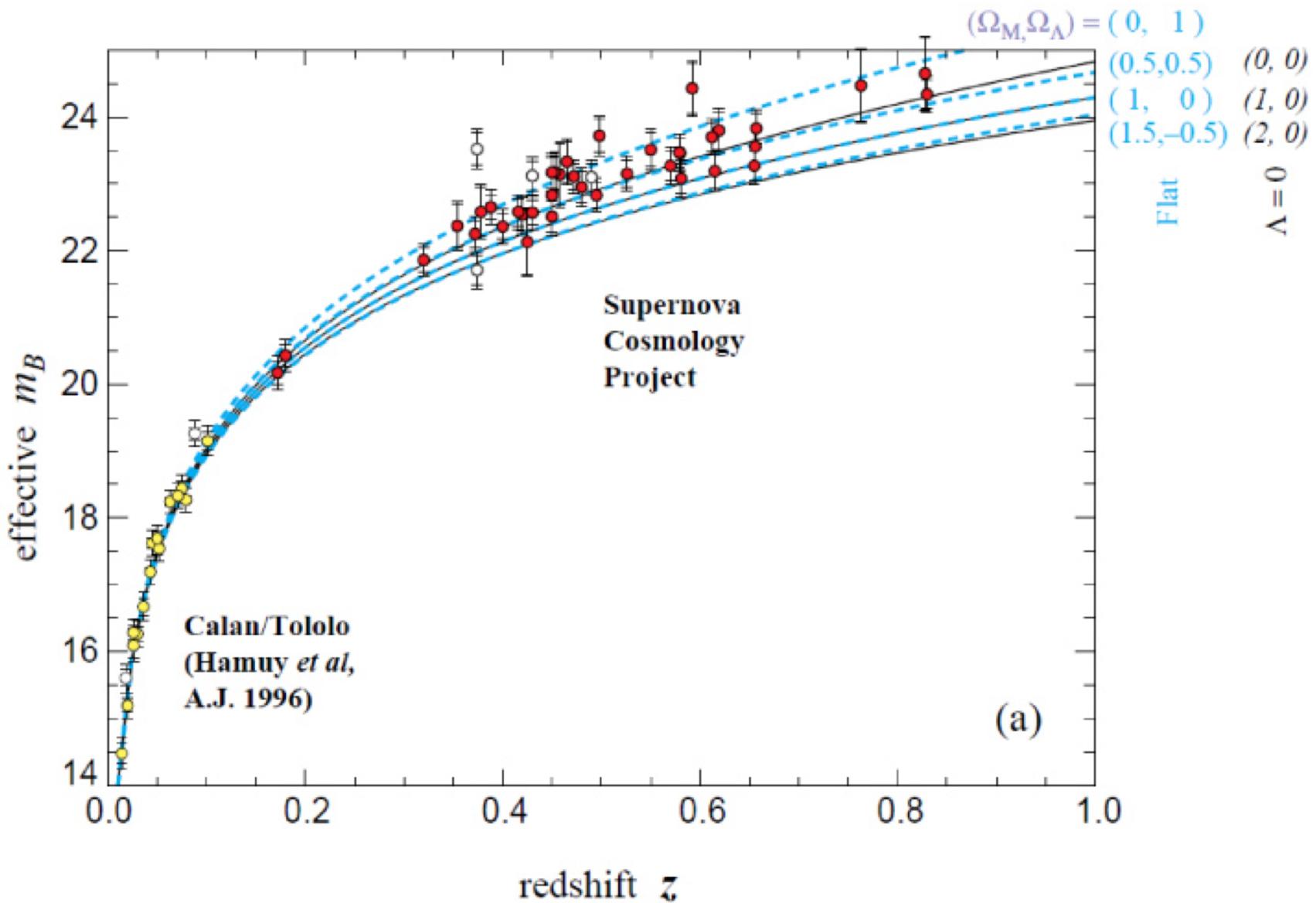


Late time structures

Dark matter is invisible but we can
see its gravitational effects
and therefore measure the evolution
of the universe



Cosmic acceleration



Dark Energy

Equation of state w :

- $w = -1$ i.e. a cosmological constant Λ
- w is constant
- w depends on time: $w(a) = w_0 + (1-a)w_a$

Gravity on large scales

- Modify GR action

Or

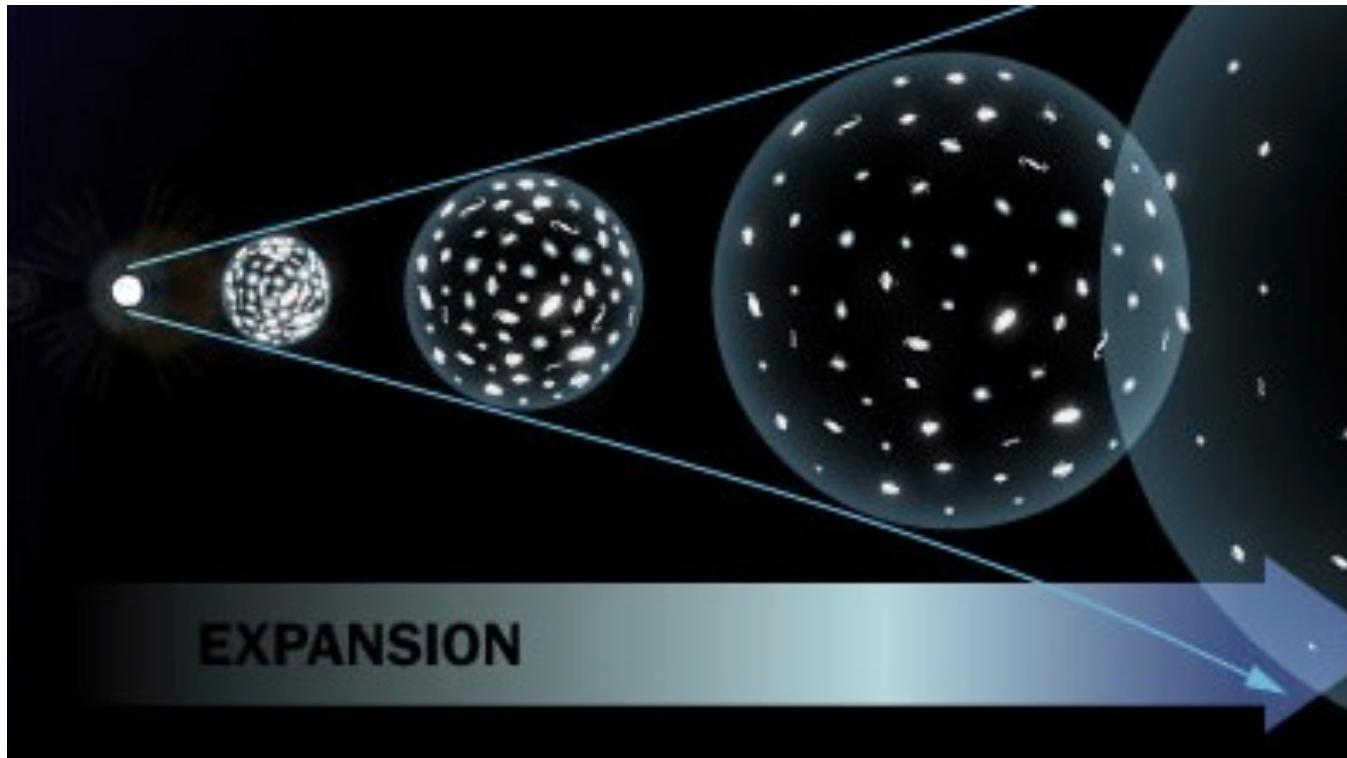
- Phenomenology of modified gravity: parametrize potentials probed by observations

$$ds^2 = a^2 [-(1 + 2\psi)d\tau^2 + (1 - 2\phi)dx^2]$$

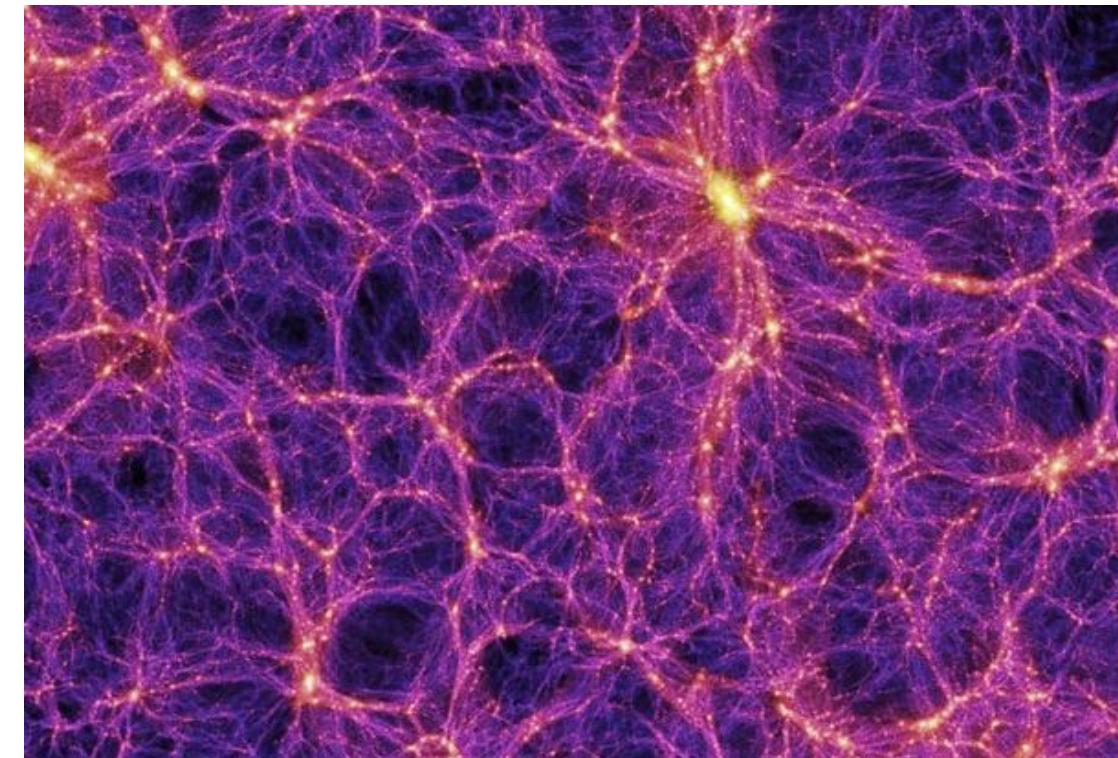
+ EFT

Probing the recent cosmic acceleration

- Evolution of the expansion



- Growth of structure



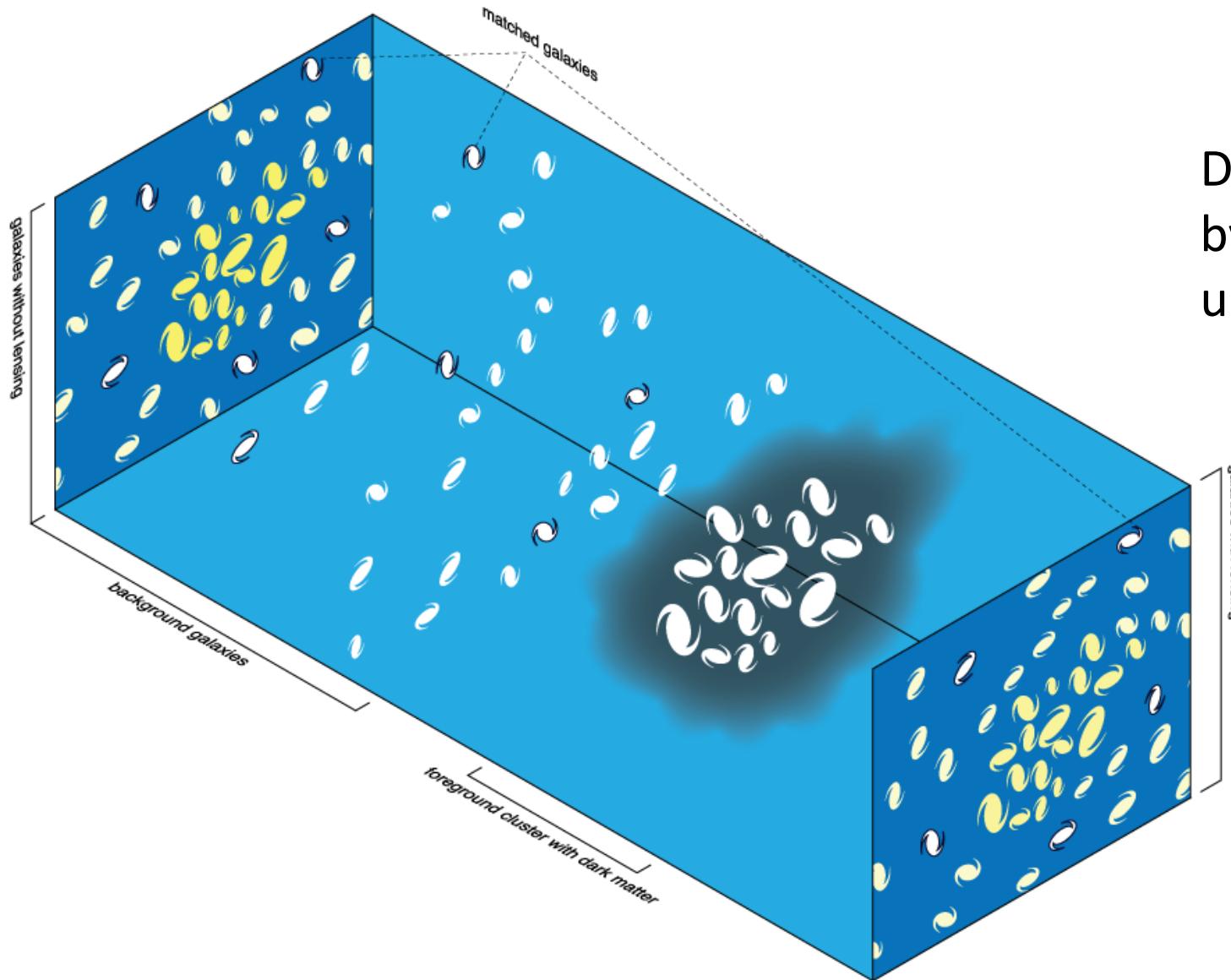
Weak lensing to probe cosmic acceleration

From galaxy surveys to cosmology

Gravitational Lensing



Weak gravitational lensing



Deformation of images of galaxies
by large scale structure in the
universe

From data to cosmology

Pictures of galaxies in different filters

Estimate ellipticities and position

2 pt correlation function

Compare with theory

Constraints on cosmological parameters

Context and future

LSST, EUCLID and WFIRST pictures

DES

KIDS

HSC

SDSS (BOSS, eBOSS), RSD

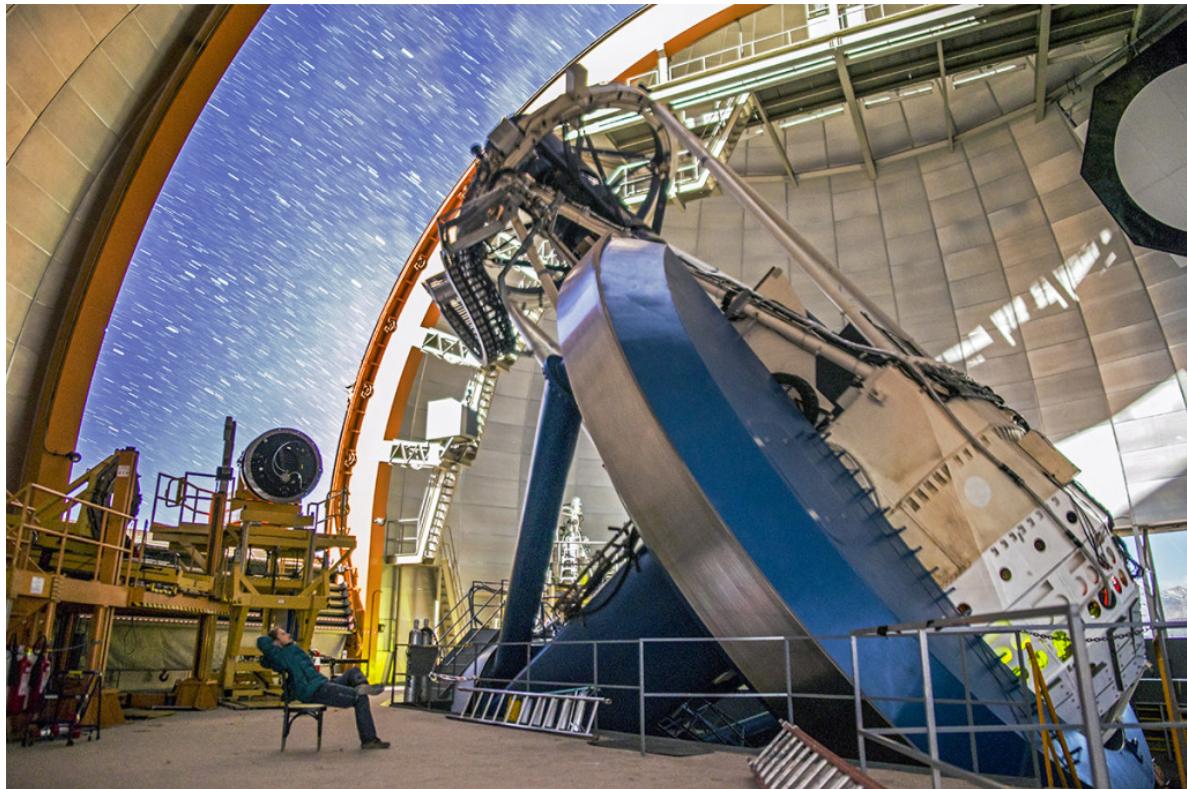
DESI, Spherex

Planck, BICEP/Keck, ACT, SPT

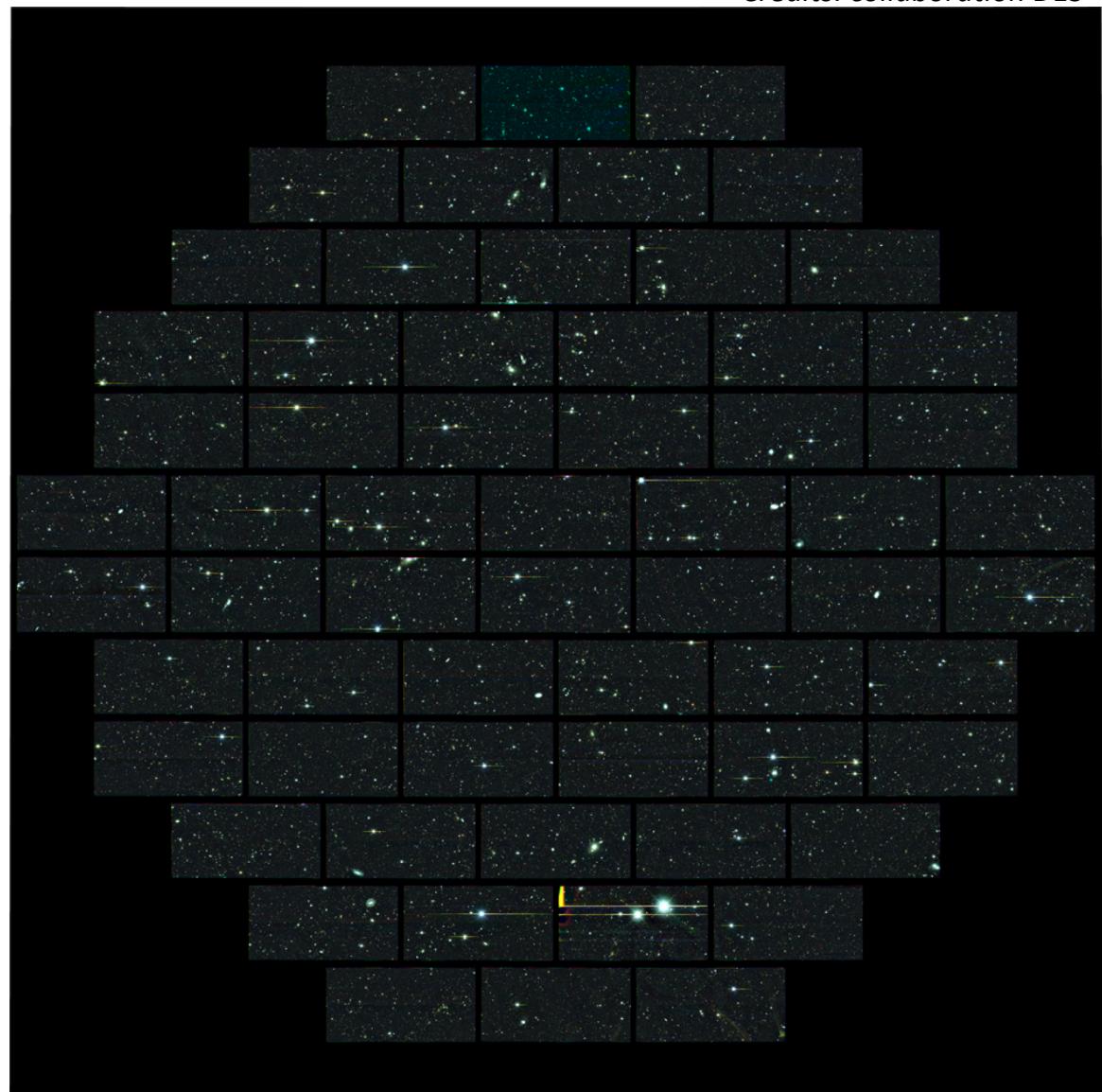
CMB experiments Litebird, Stage 4

The Dark Energy Survey

Credits: collaboration DES

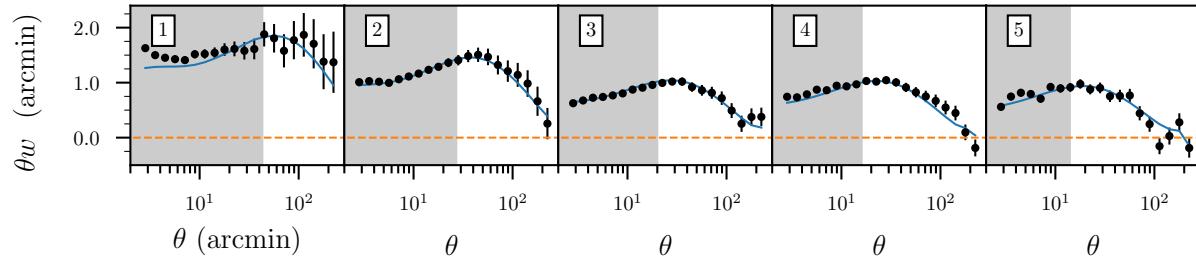
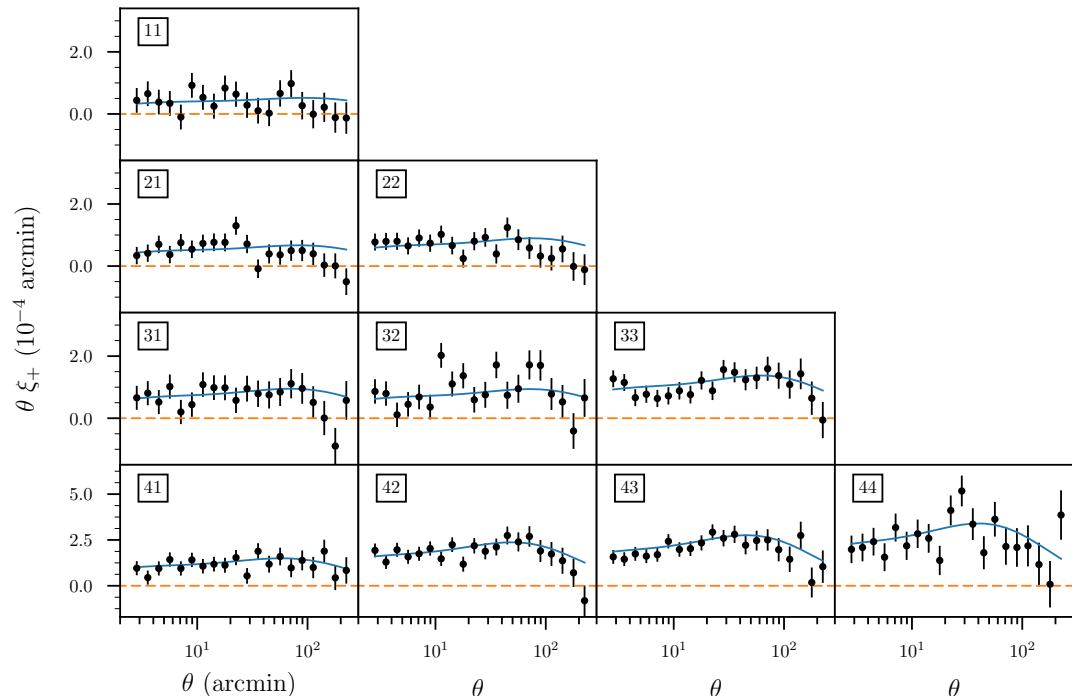


Credits: collaboration DES

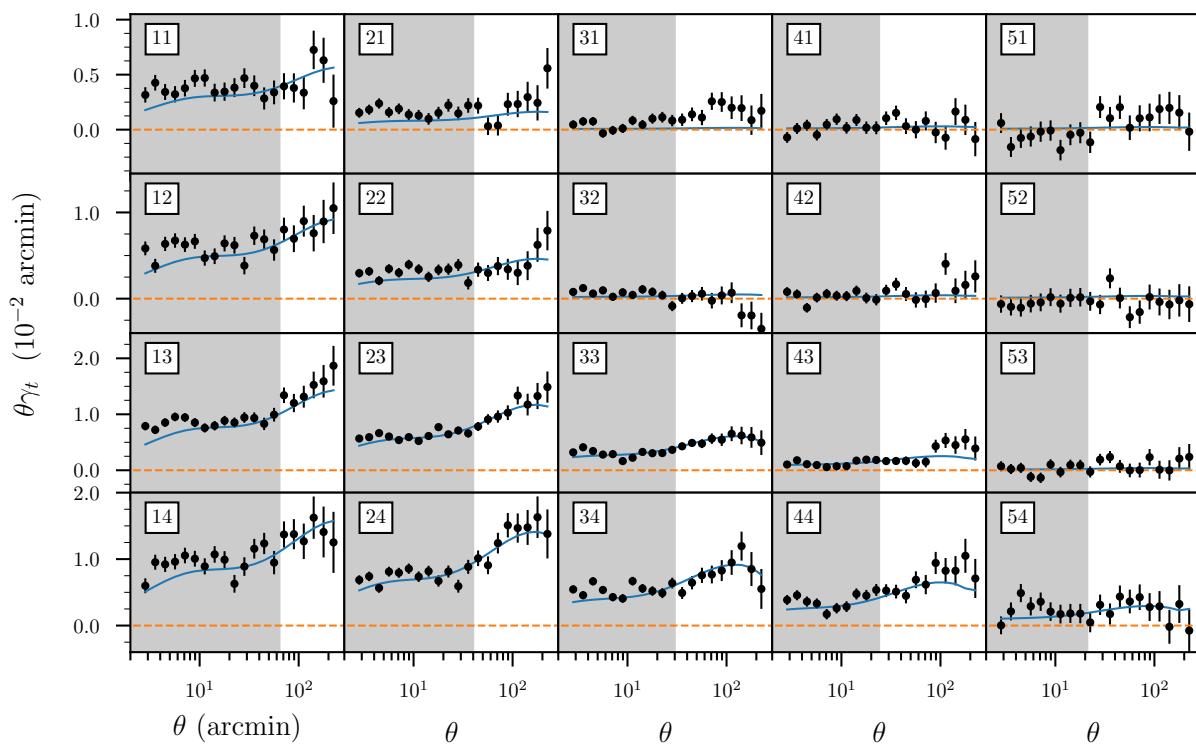


Dark energy with DES 1st year of observation data

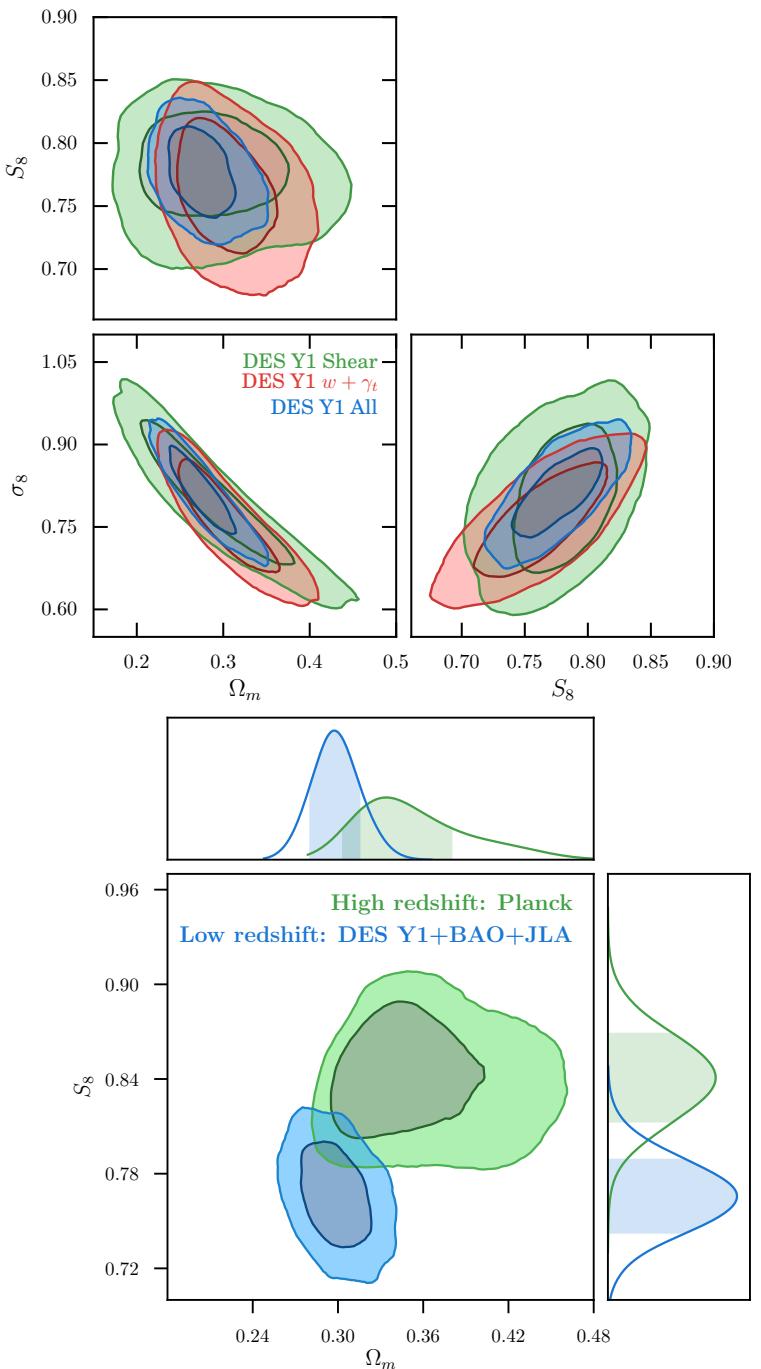
DES collaboration, Phys. Rev. D 98, 043526 (2018)



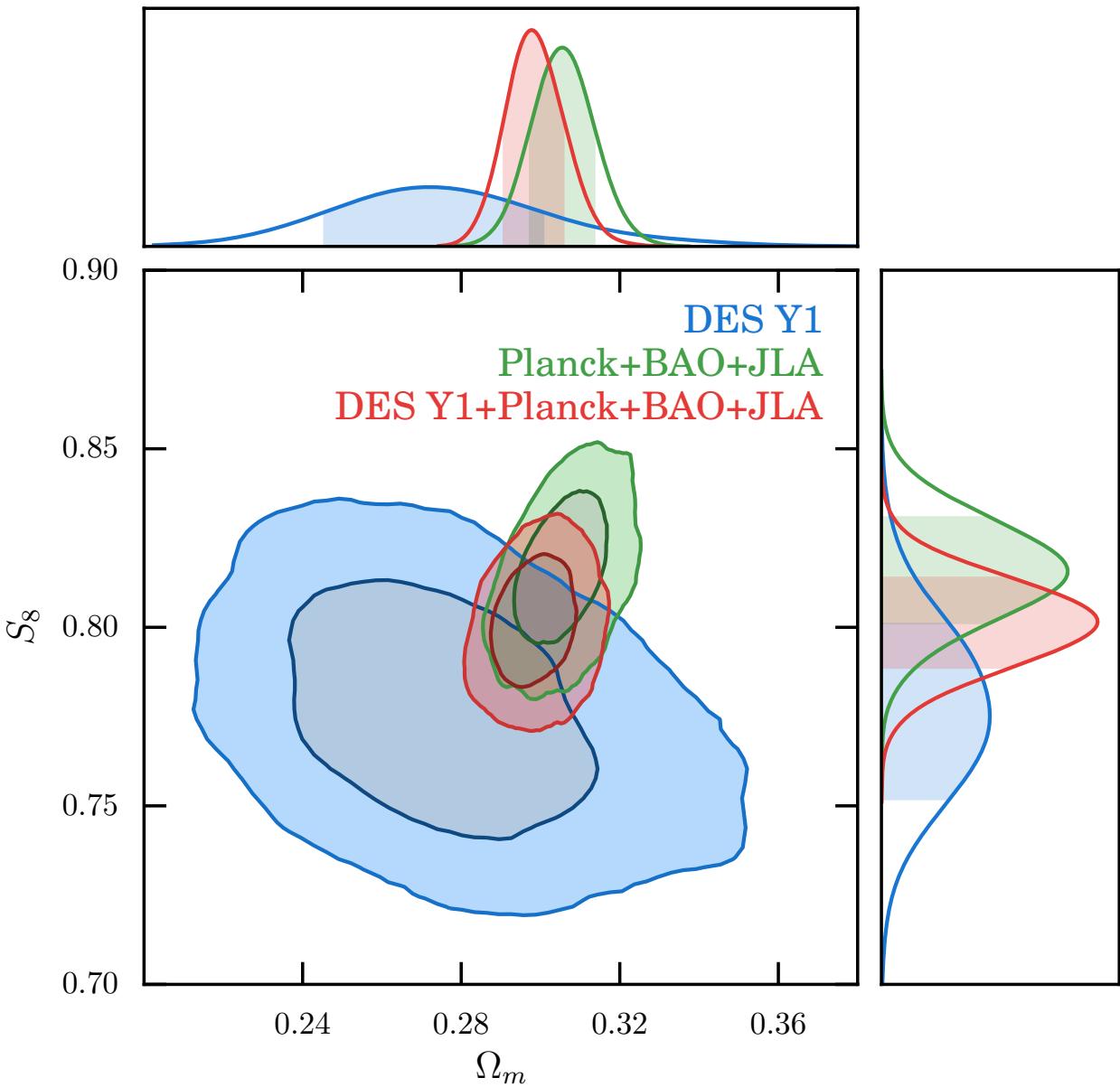
◆ DES Y1 fiducial
— best-fit model
■ scale cuts



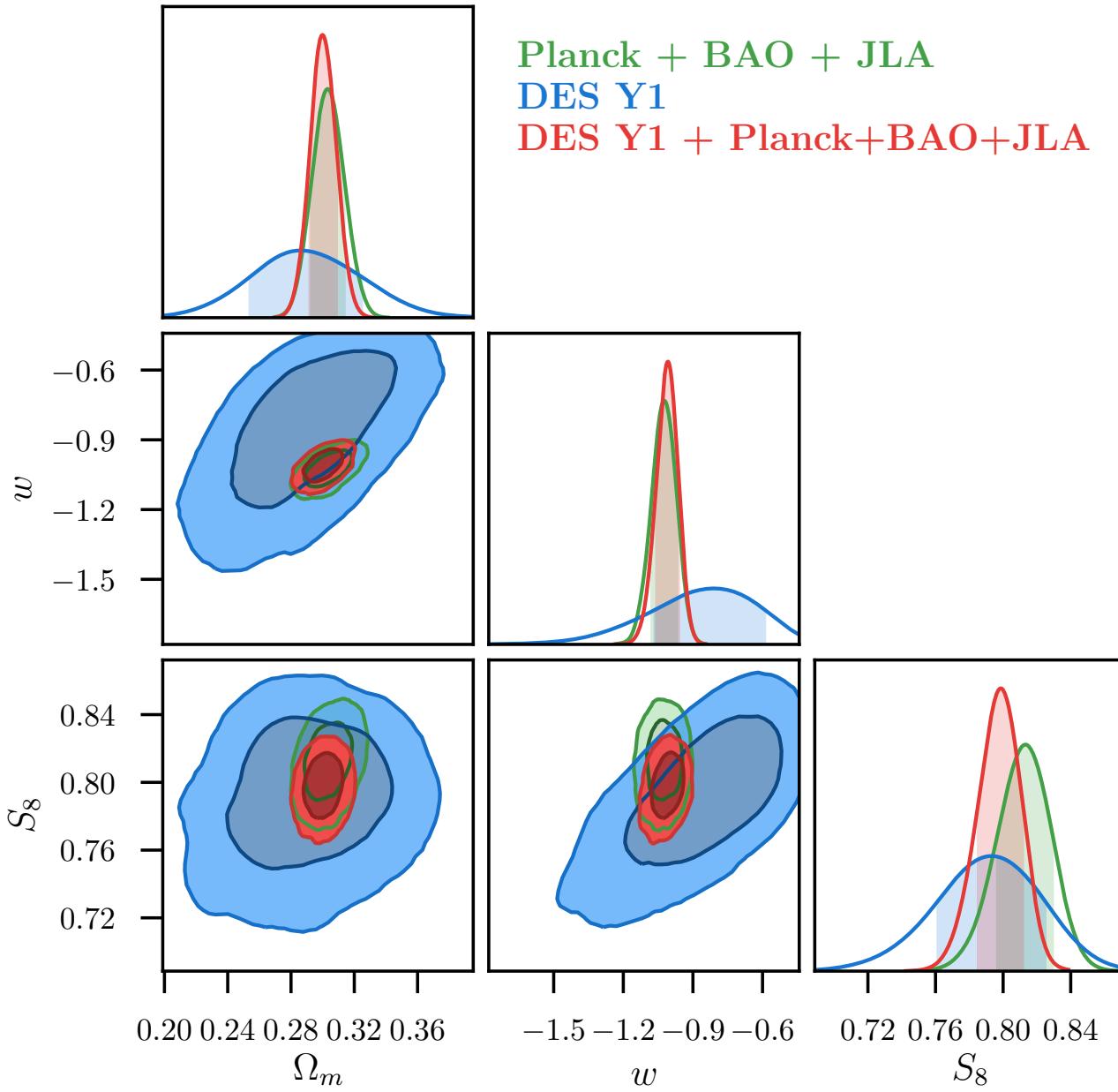
Λ CDM



From DES collaboration, PRD, 2018

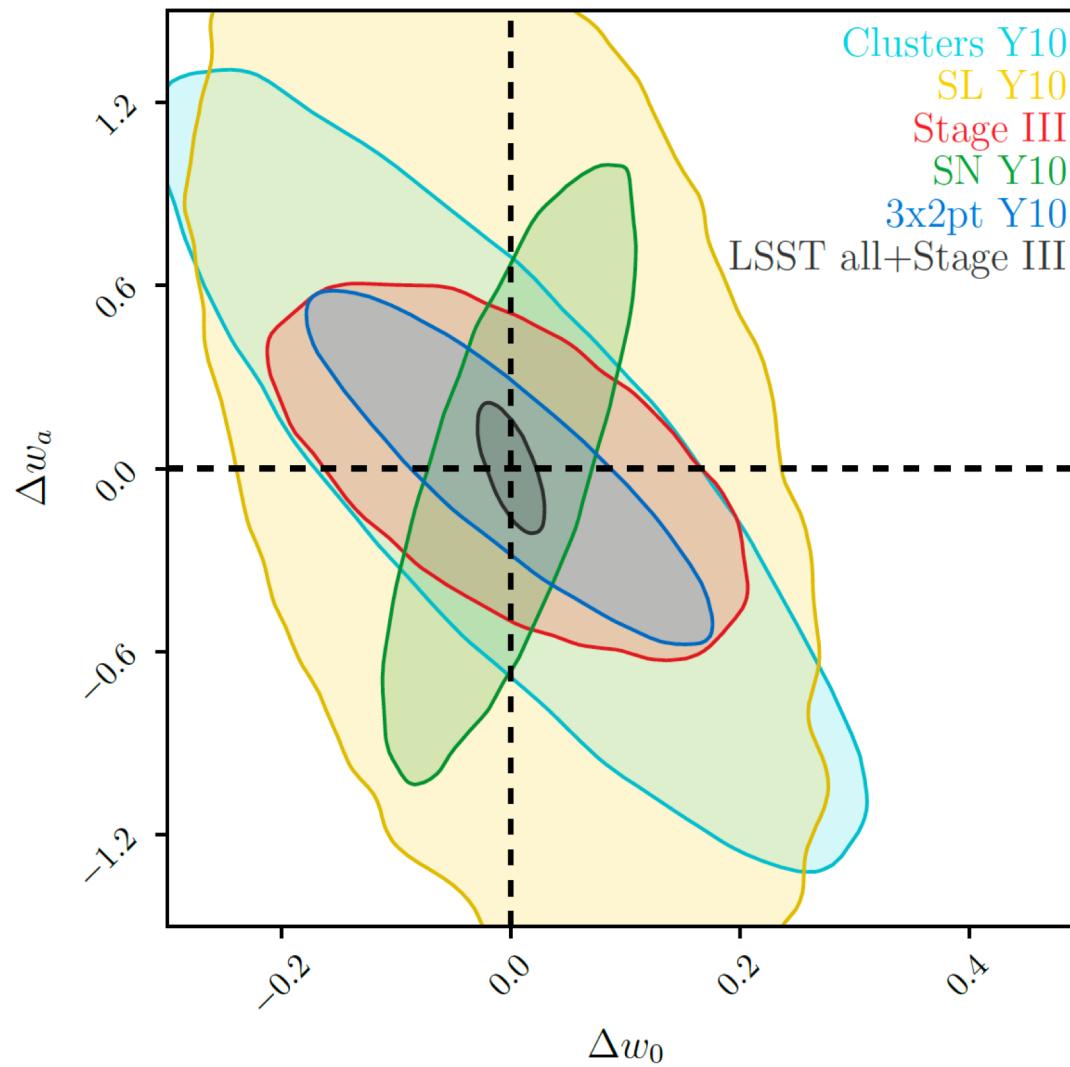


wCDM



From DES collaboration, PRD, 2018

Example of forecast: LSST



Testing gravity on large scales

Phenomenology of modified gravity

$$k^2 \psi = -4\pi G a^2 (1 + \mu(a, k)) \rho \delta$$

$$k^2 (\psi + \phi) = -8\pi G a^2 (1 + \Sigma(a, k)) \rho \delta$$



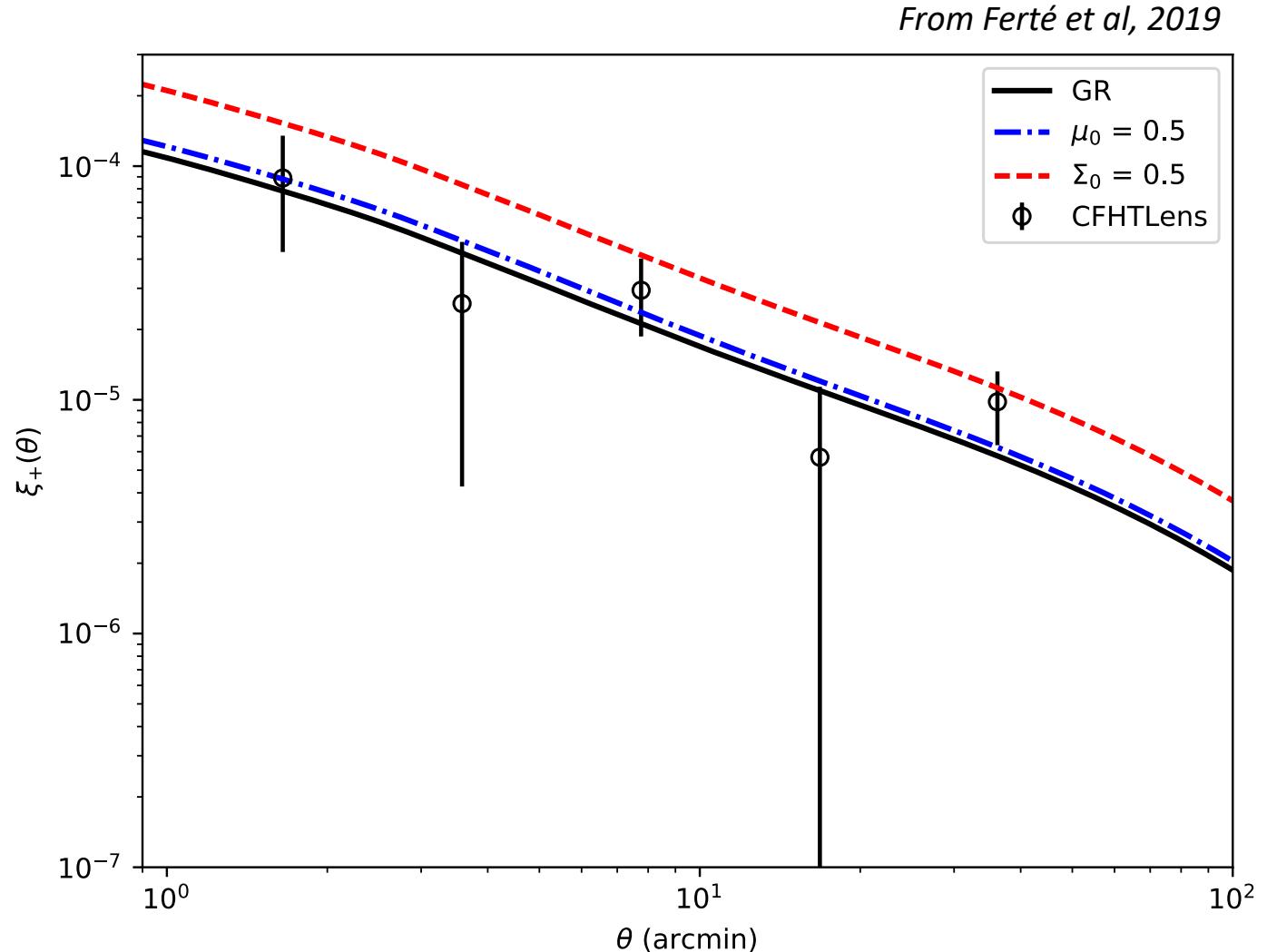
Parametrization of deviations in this work:

$$\mu(z) = \mu_0 \frac{\Omega_\Lambda(z)}{\Omega_\Lambda}, \quad \Sigma(z) = \Sigma_0 \frac{\Omega_\Lambda(z)}{\Omega_\Lambda}$$

Testing gravity with cosmic shear

Ferté, Kirk, Liddle, Zuntz, Phys. Rev. D 99, 083512 (2019)

- Use of:
- Cosmossis
 - MGCamb
 - Available shear likelihoods:
CFHTLens and DES-SV

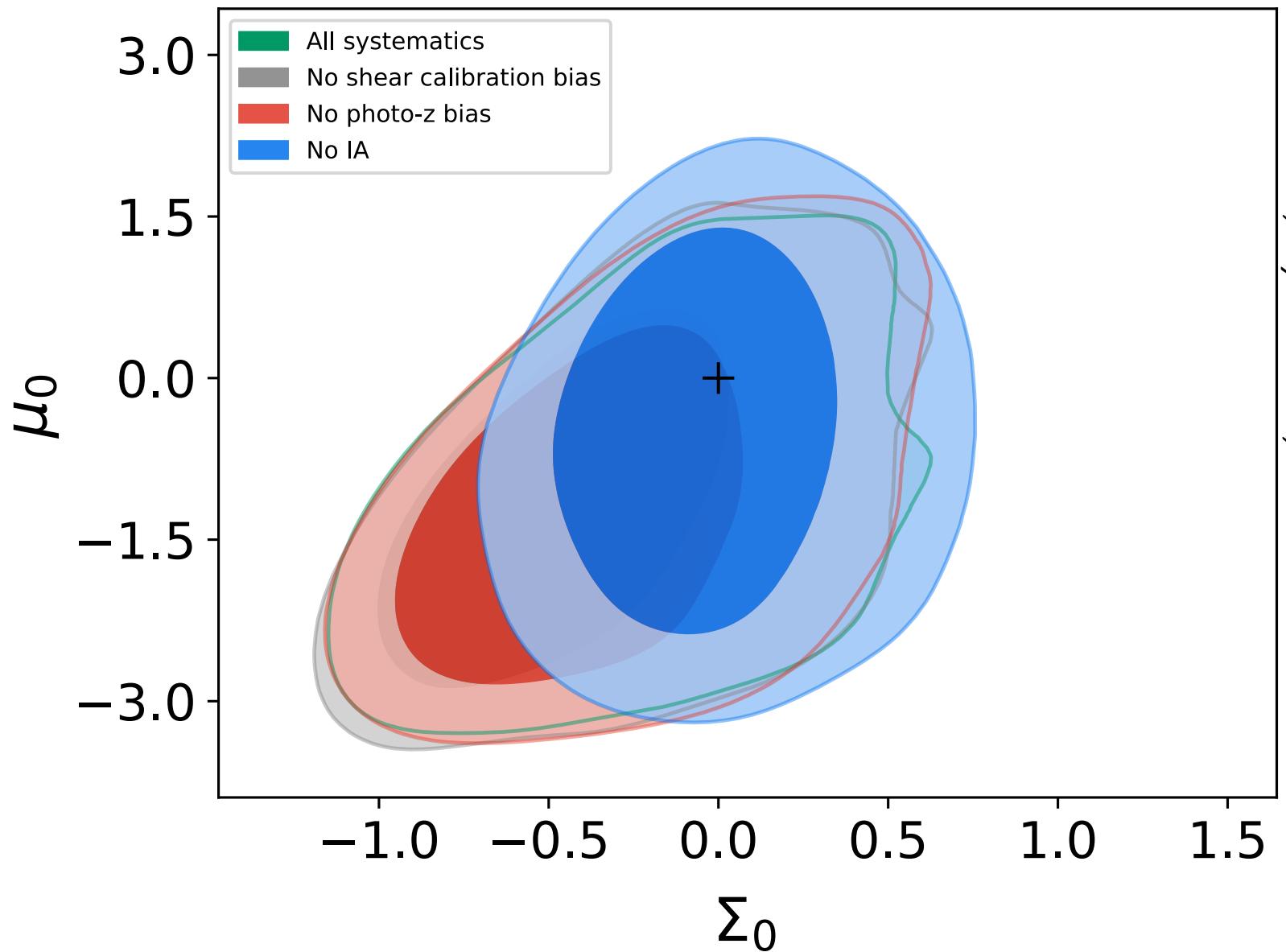


Testing gravity with cosmic shear - Impact of systematics

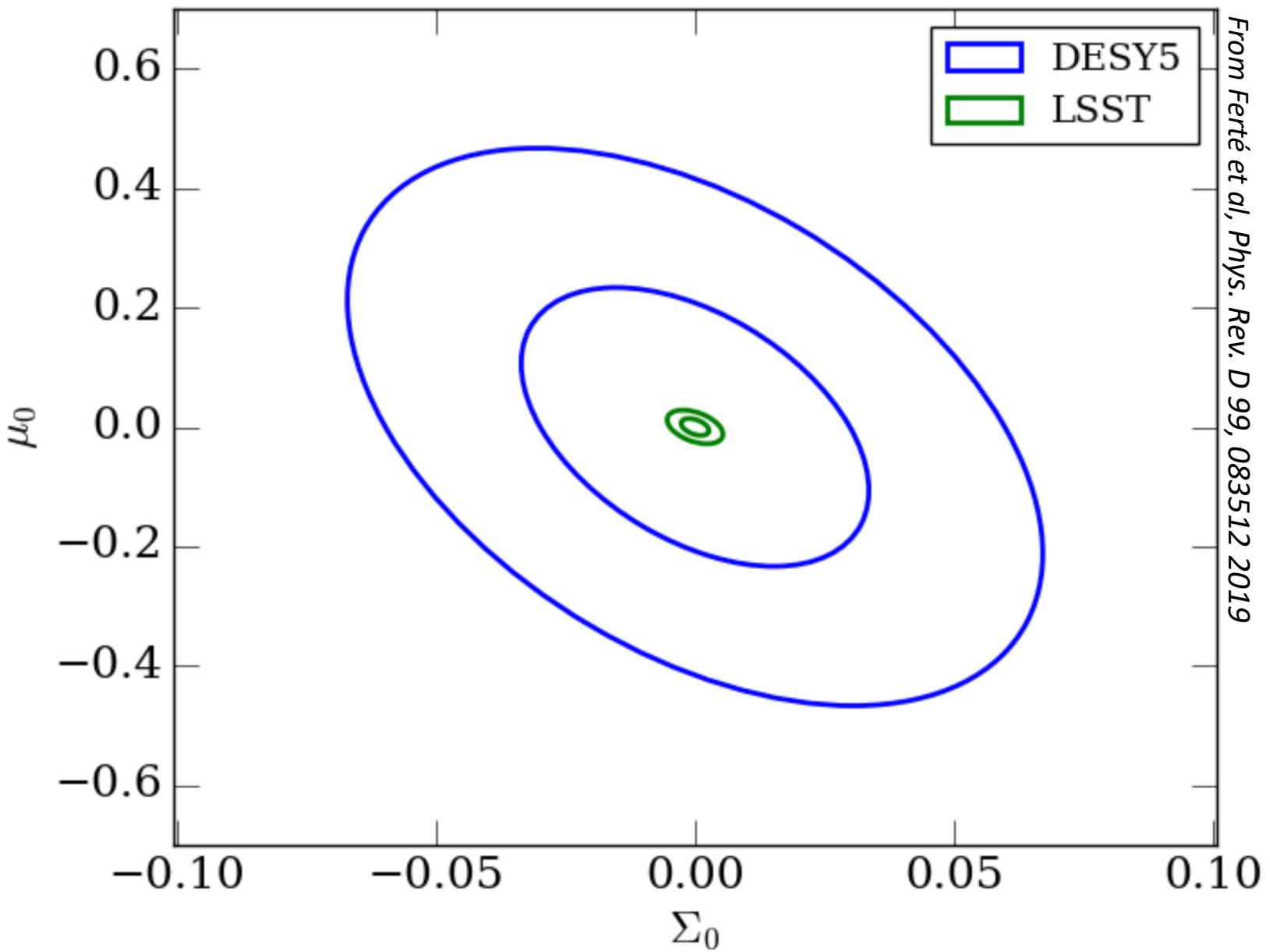
Modelisation of systematics
with a nuisance parameter

e.g. intrinsic alignment =

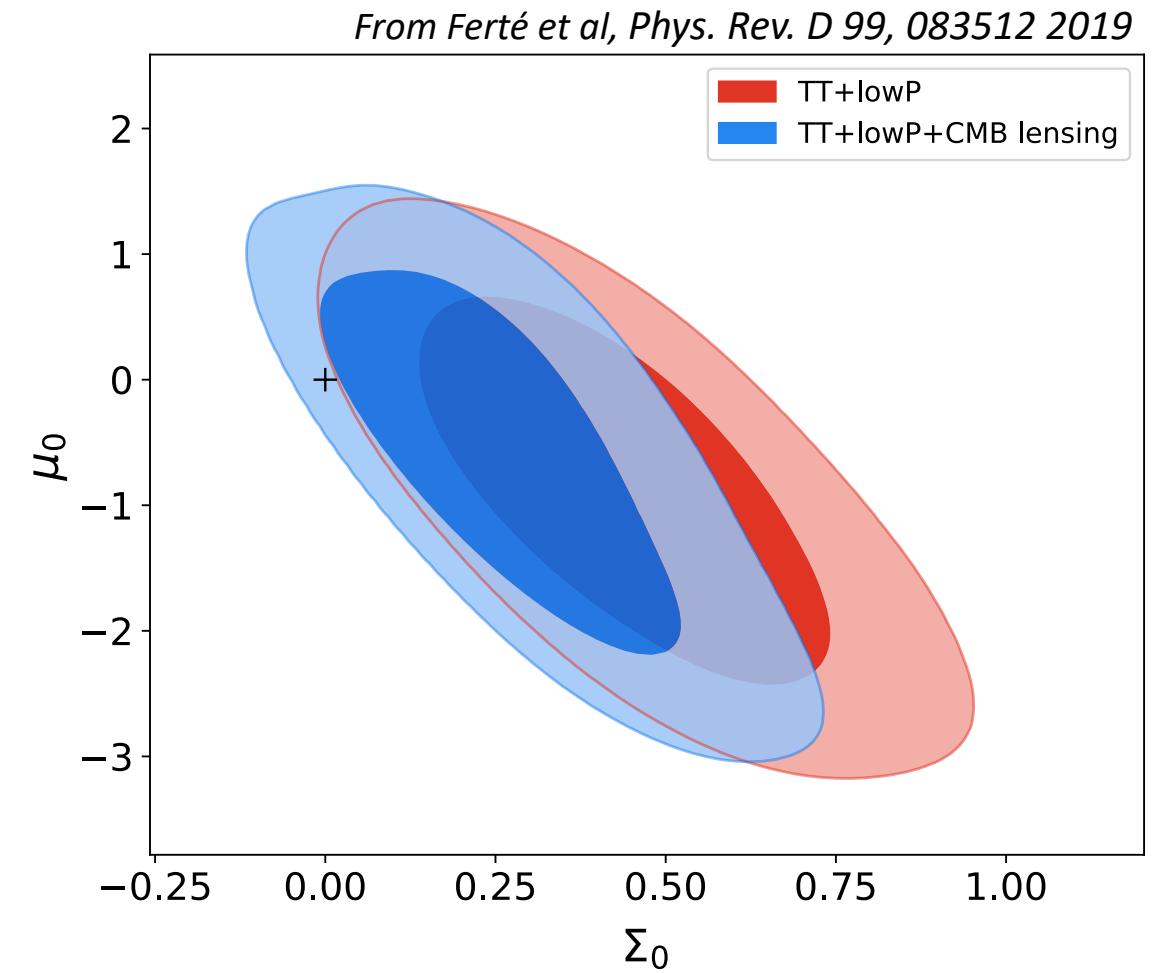
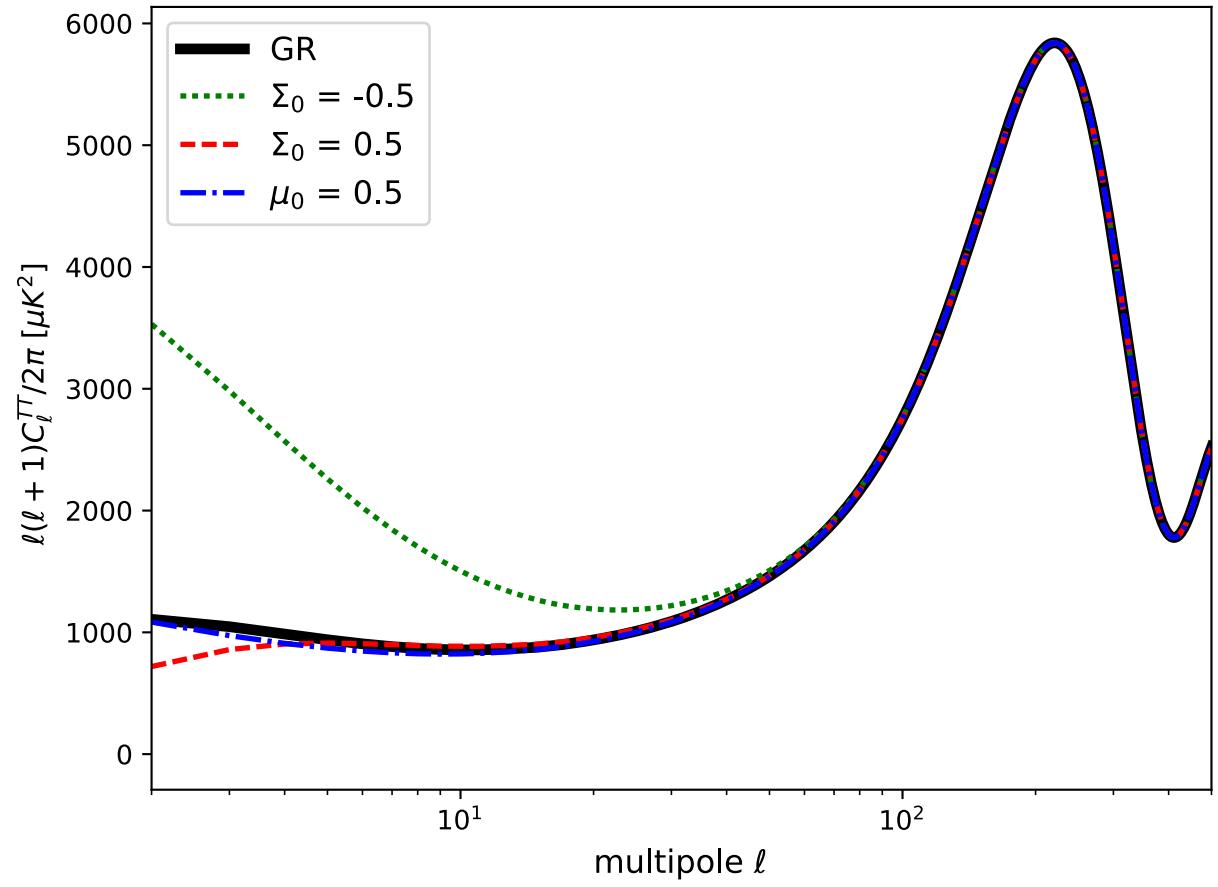
$$P_{IA}(k, z) \propto A_{IA} P(k, z) / D(z)$$



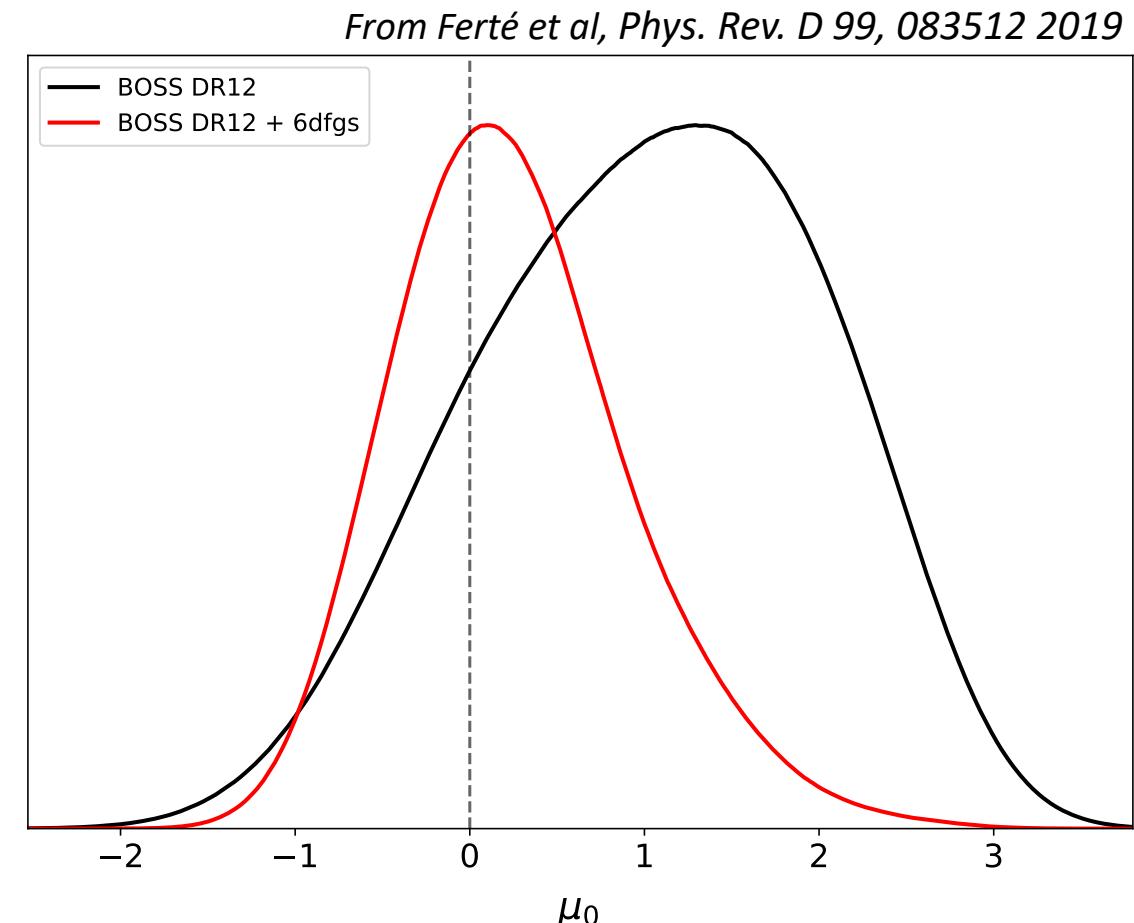
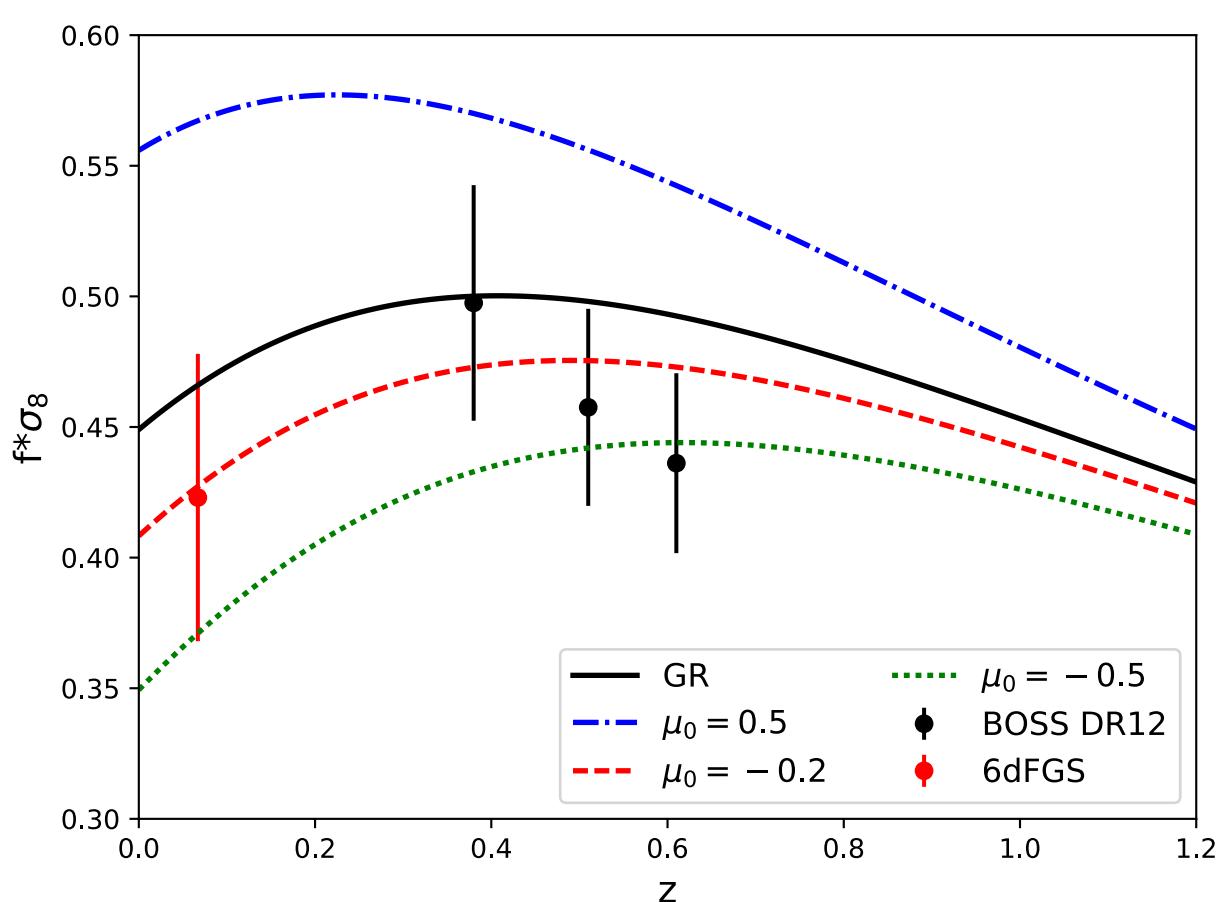
Testing gravity with cosmic shear - Forecasts



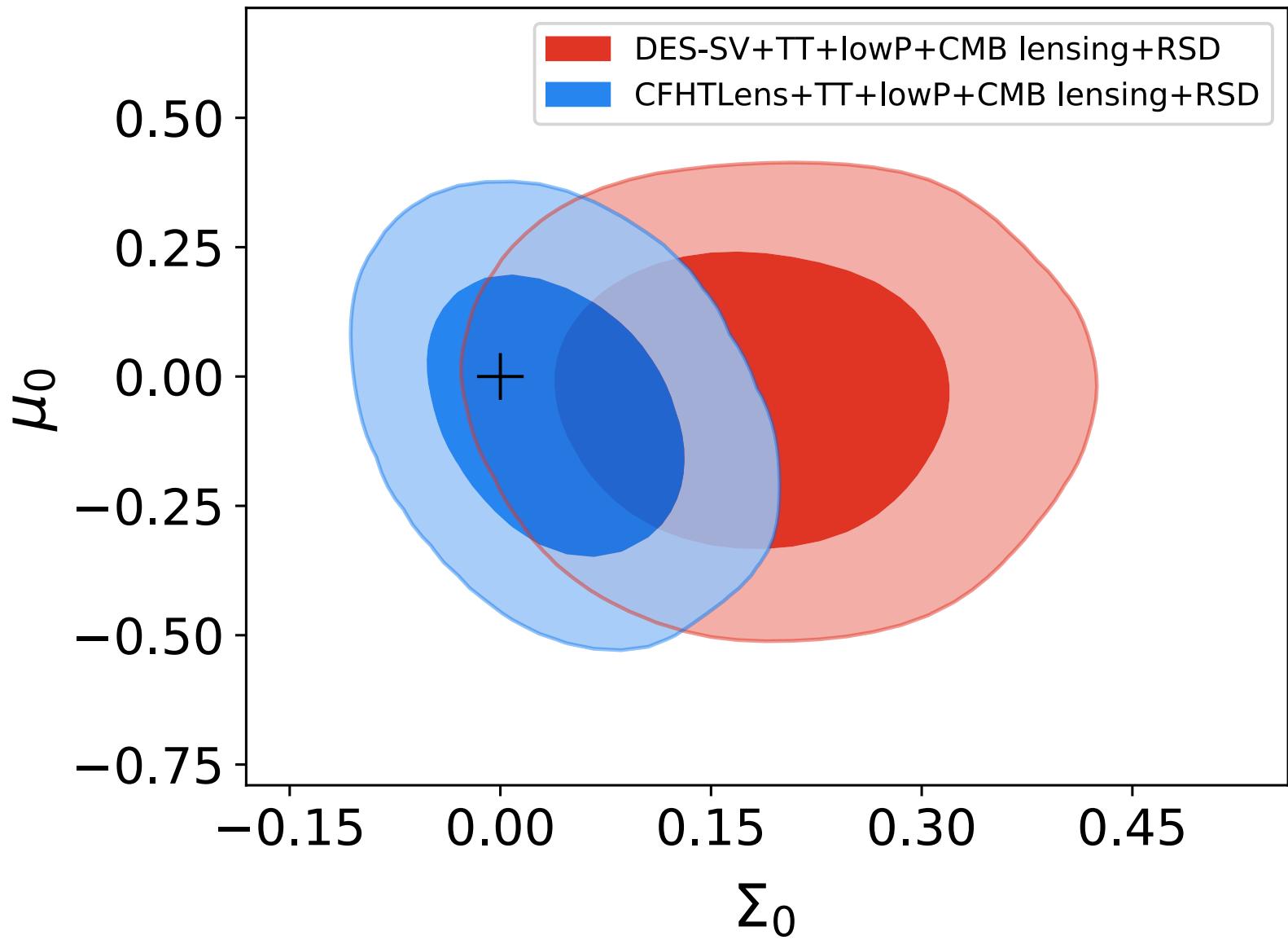
Testing gravity with CMB temperature and polarization



Testing gravity with RSD



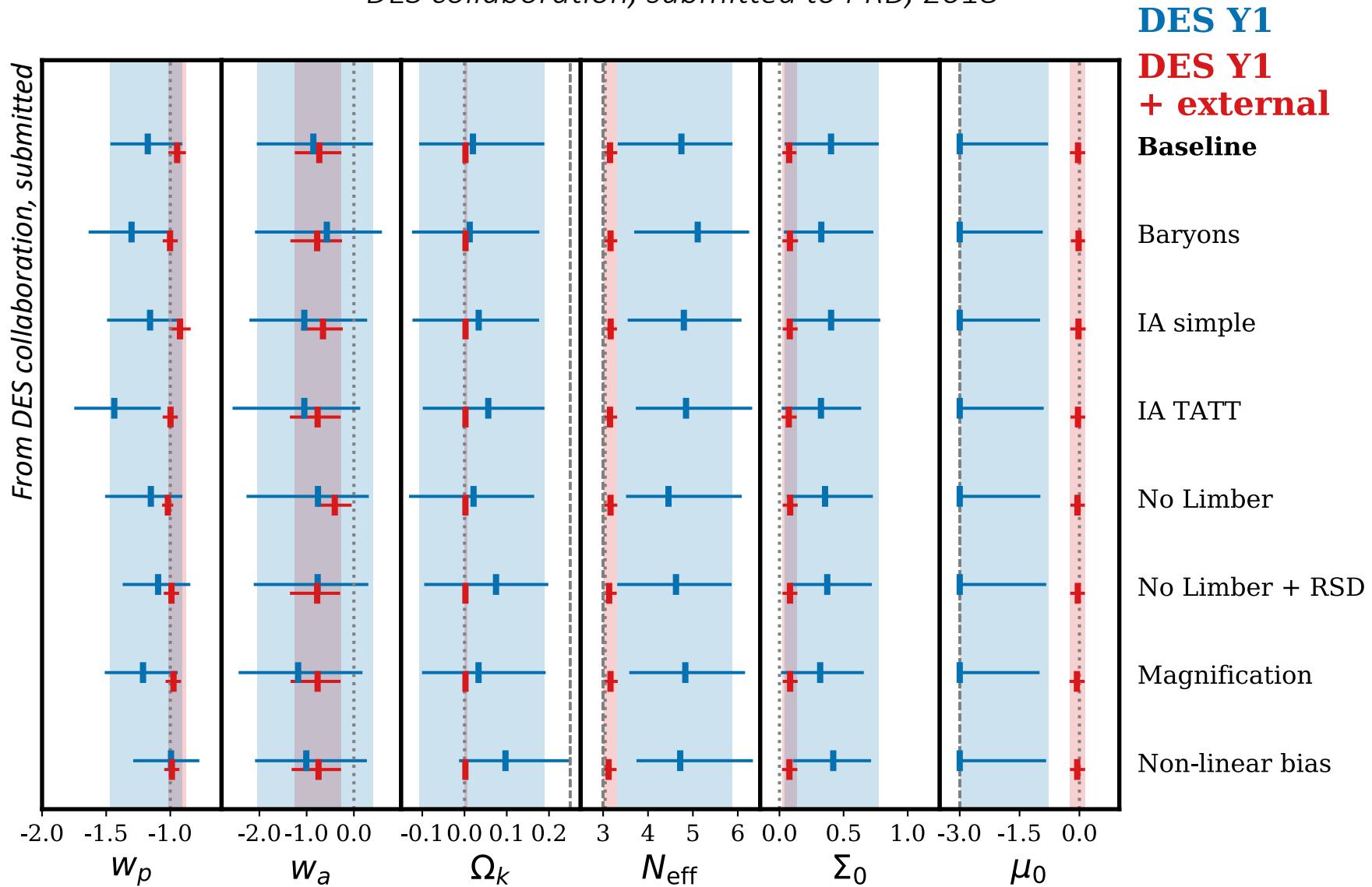
Testing gravity combining observables



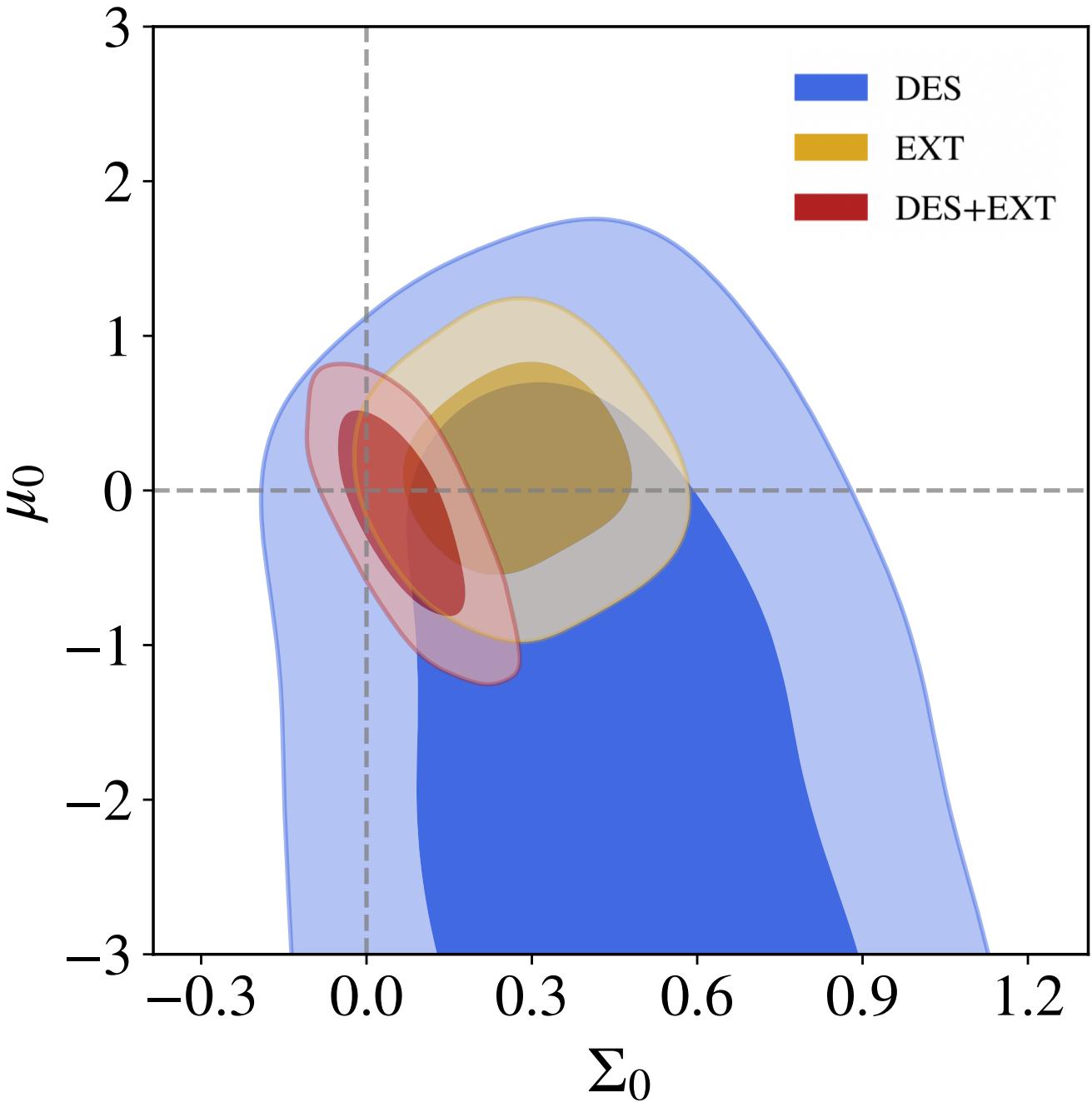
From Ferté et al, Phys. Rev. D 99, 083512 2019

Testing gravity with DES 1st year of observation data

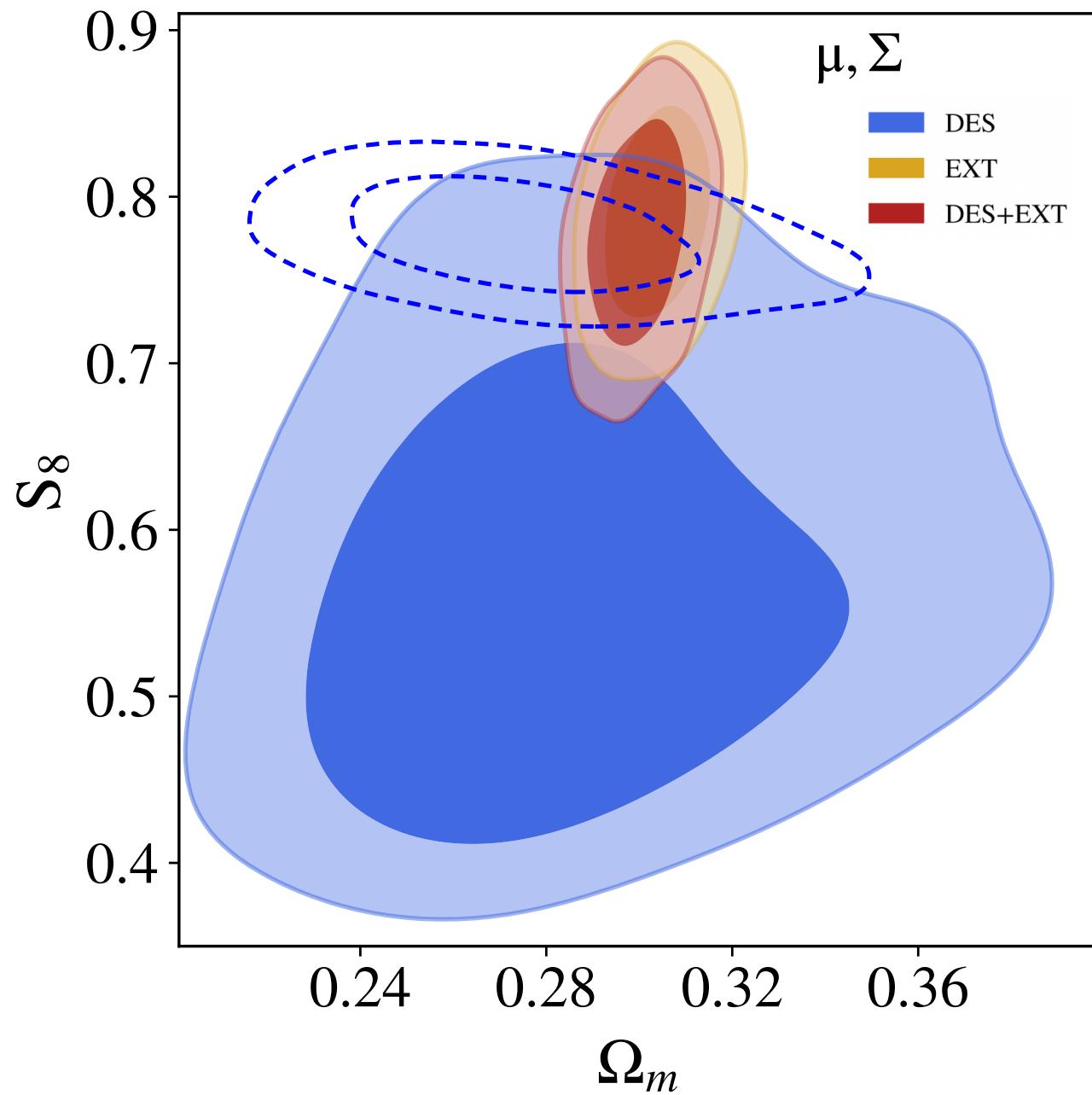
DES collaboration, submitted to PRD, 2018



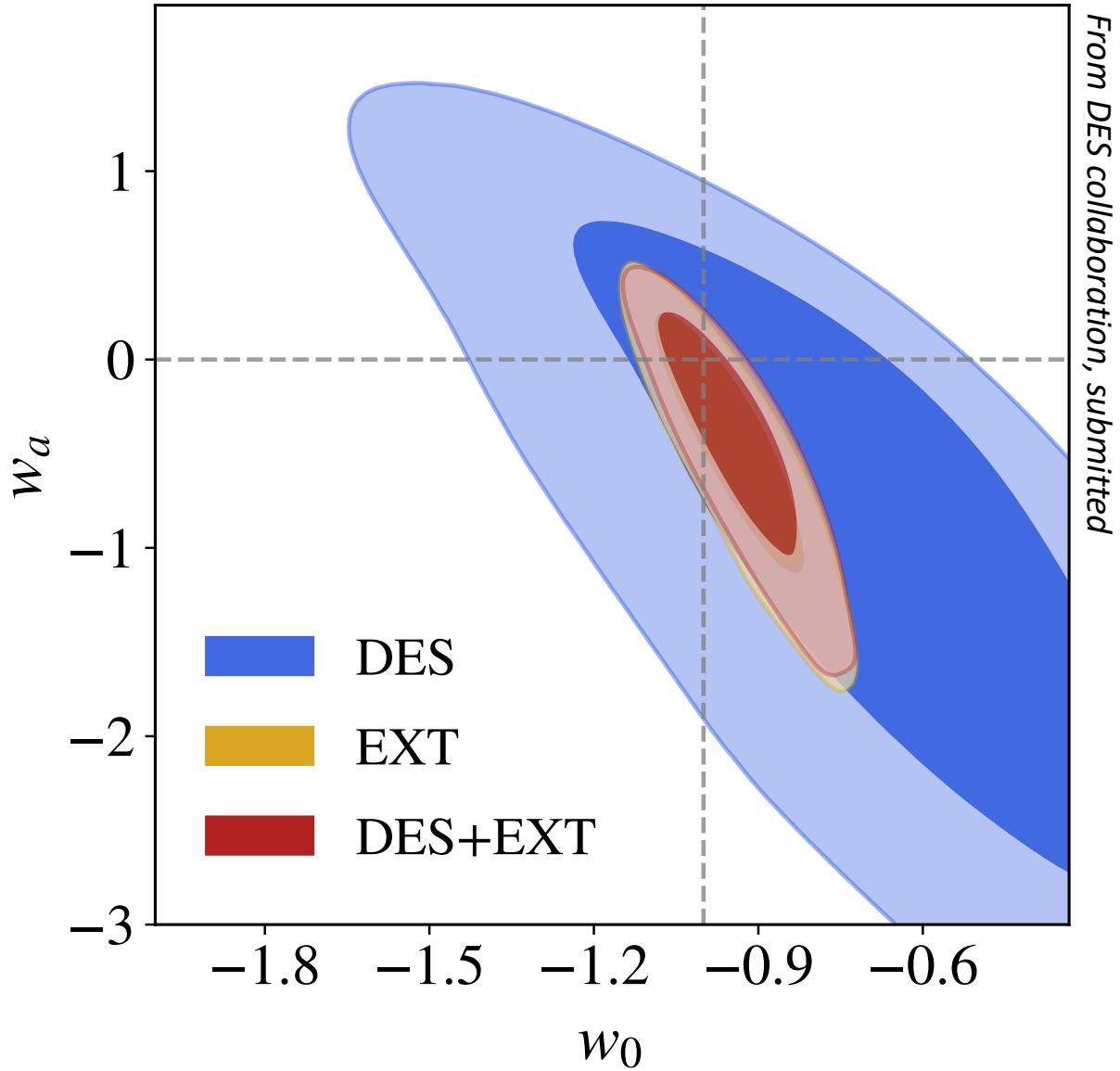
From DES collaboration, submitted



From DES collaboration, submitted



Other extension to wCDM models: a dynamical dark energy



New DES data release: DES Y3

More tiles: more statistics

More fsky

Extensions to LambdaCDM model

Extensions analysis team: ~15 people now. more models and combination with other observables

W0wa, omega_k, extra relat part, MG,

High precision weak lensing measurements
New detectors, new instrumental effects

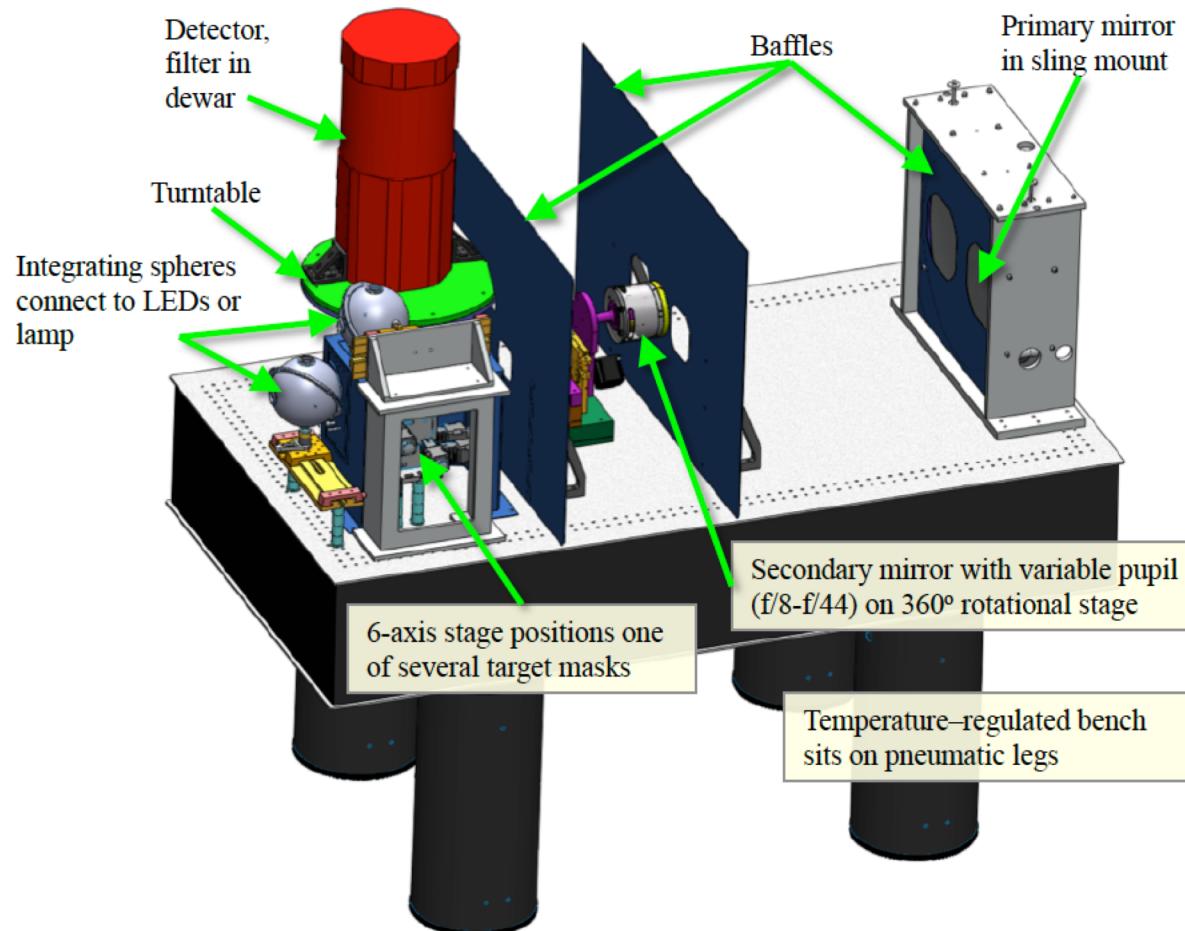
Understanding detector effects: beyond first order effect

Example of effects:

- Image persistent
- Non linear effects

Precision Projector Laboratory

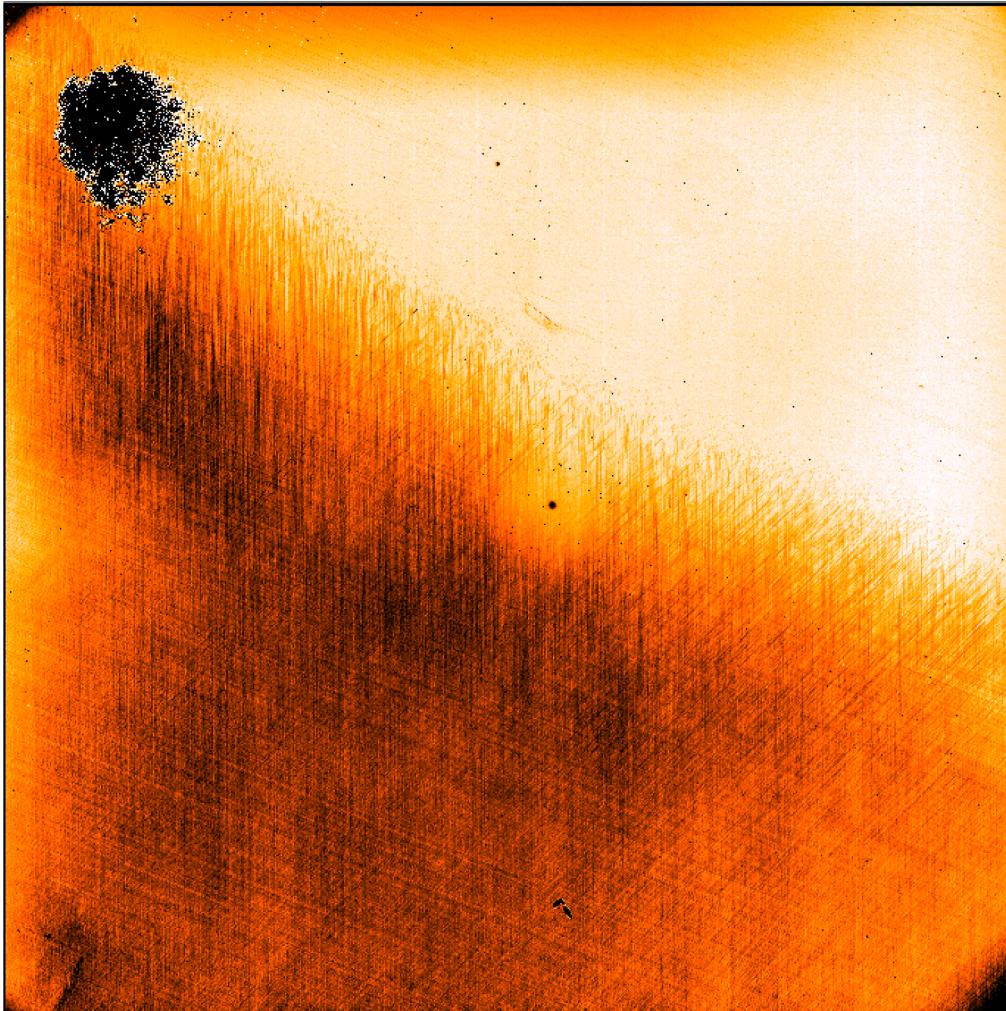
Projection of points mimicking galaxies on sensors



From Shapiro et al., 2017

Effects studied at PPL

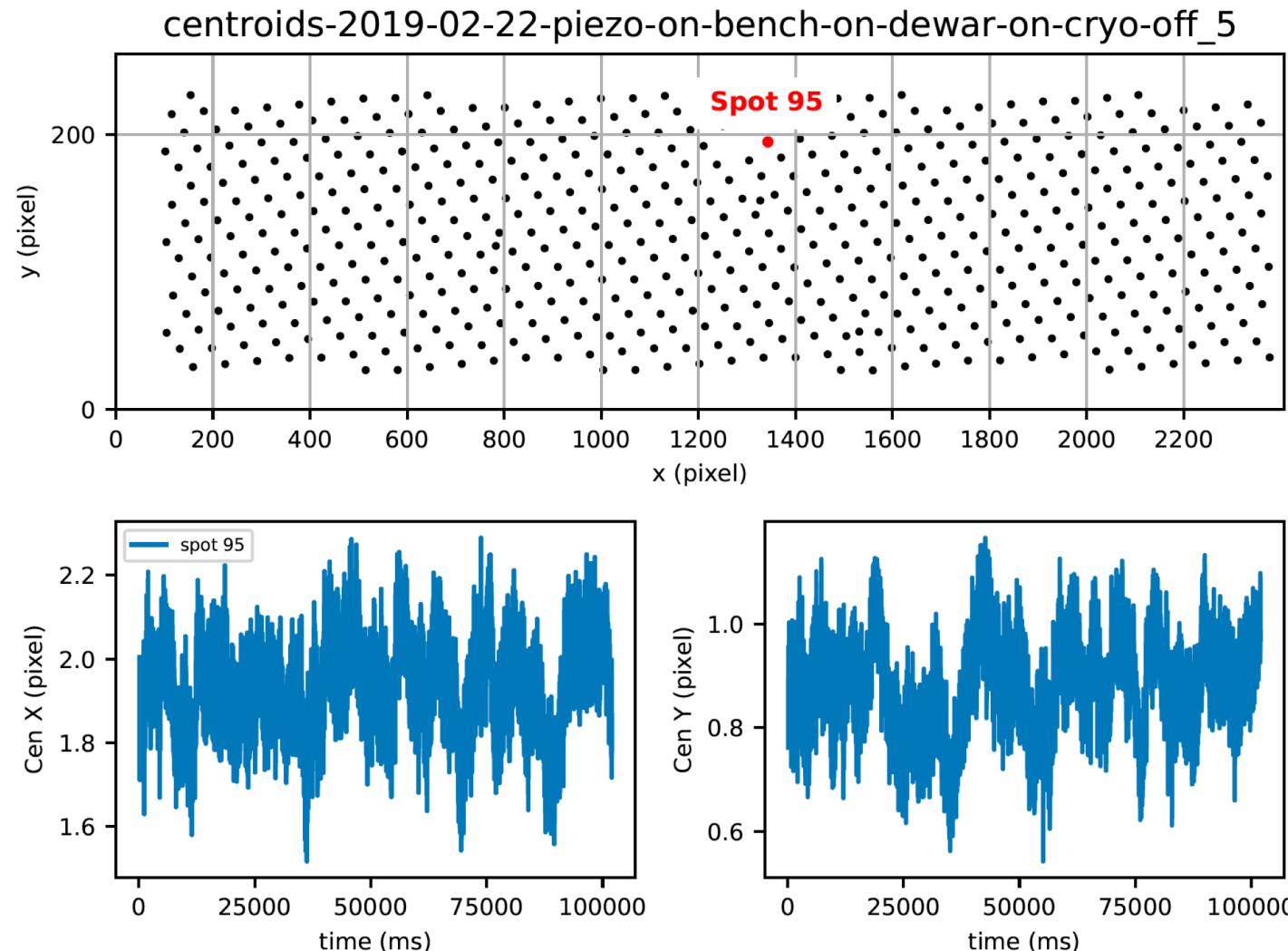
Cross hatch



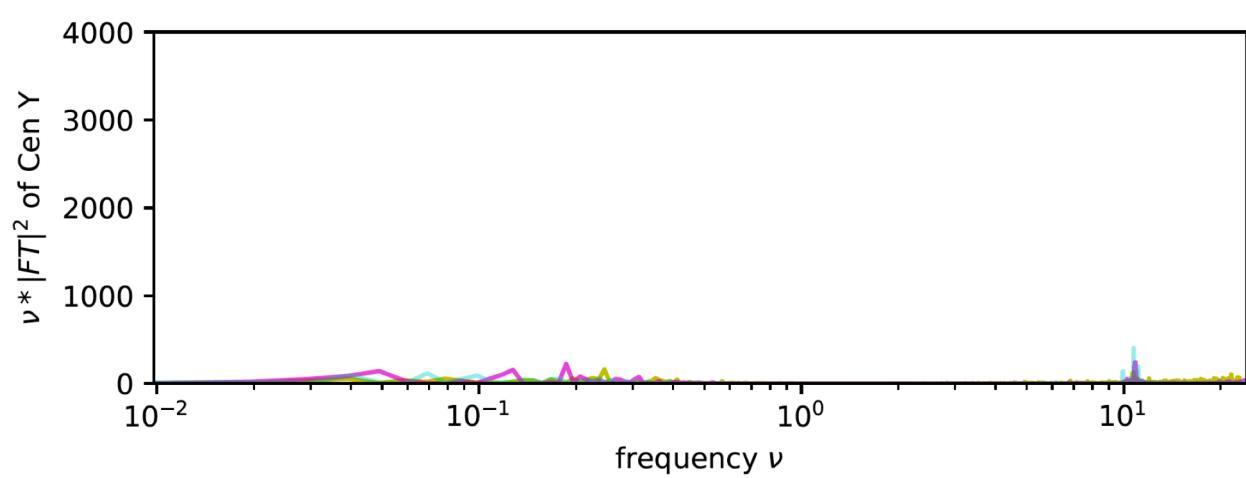
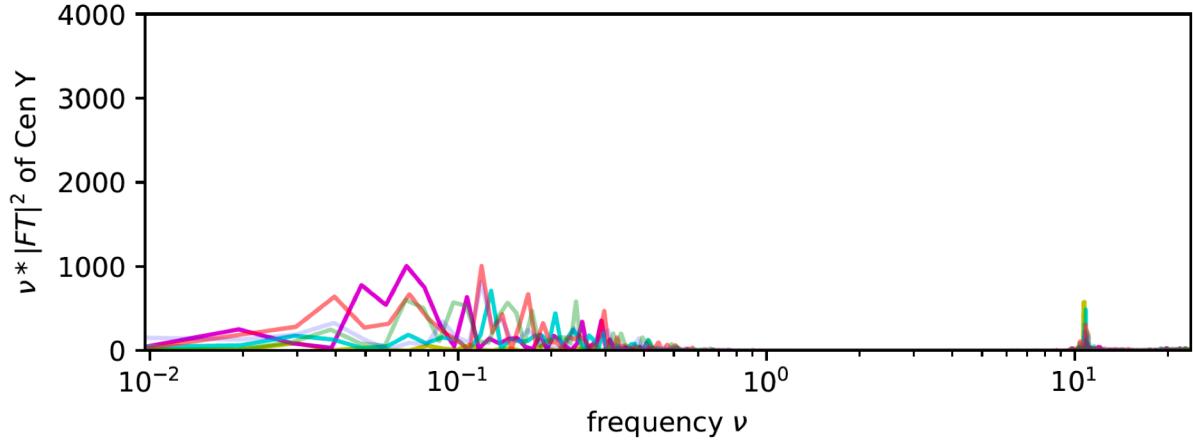
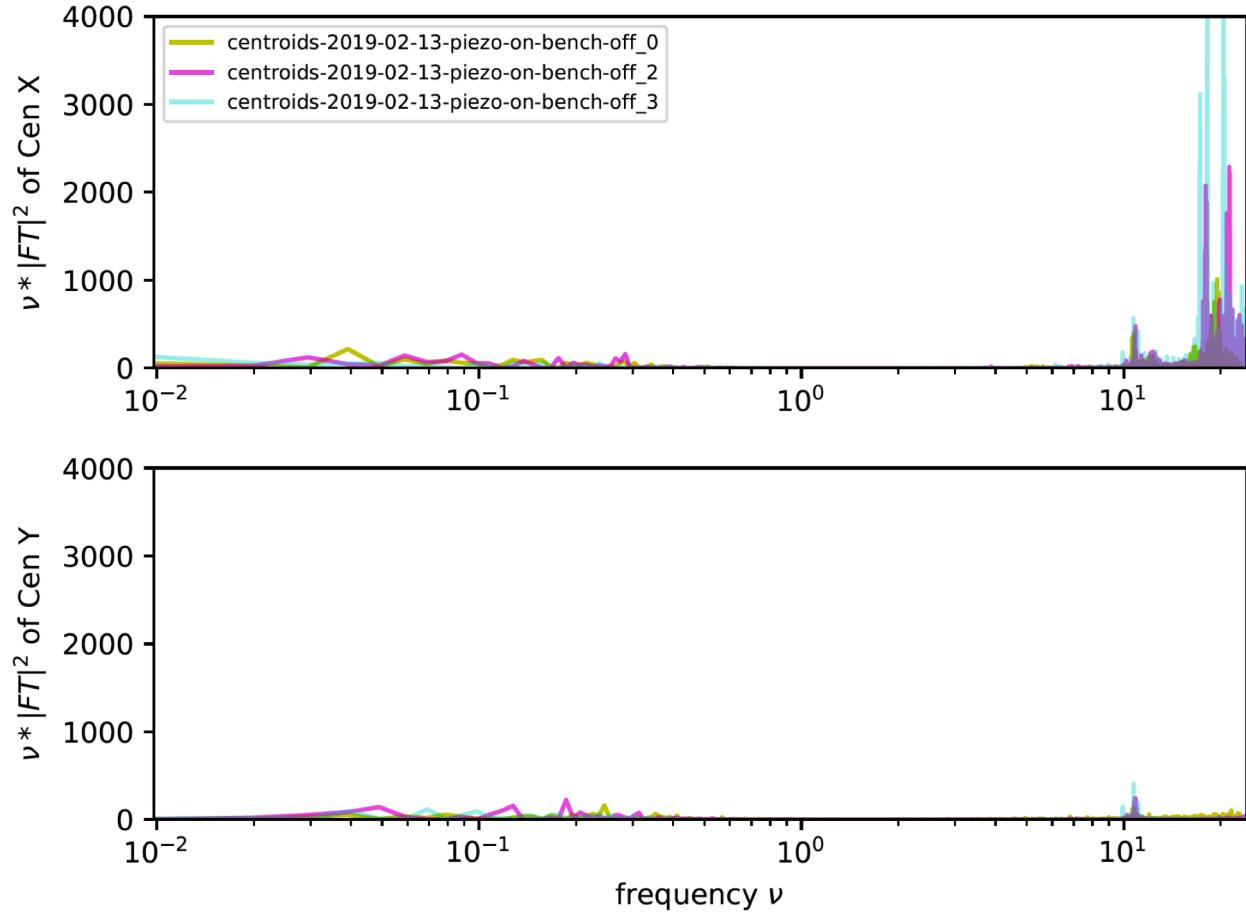
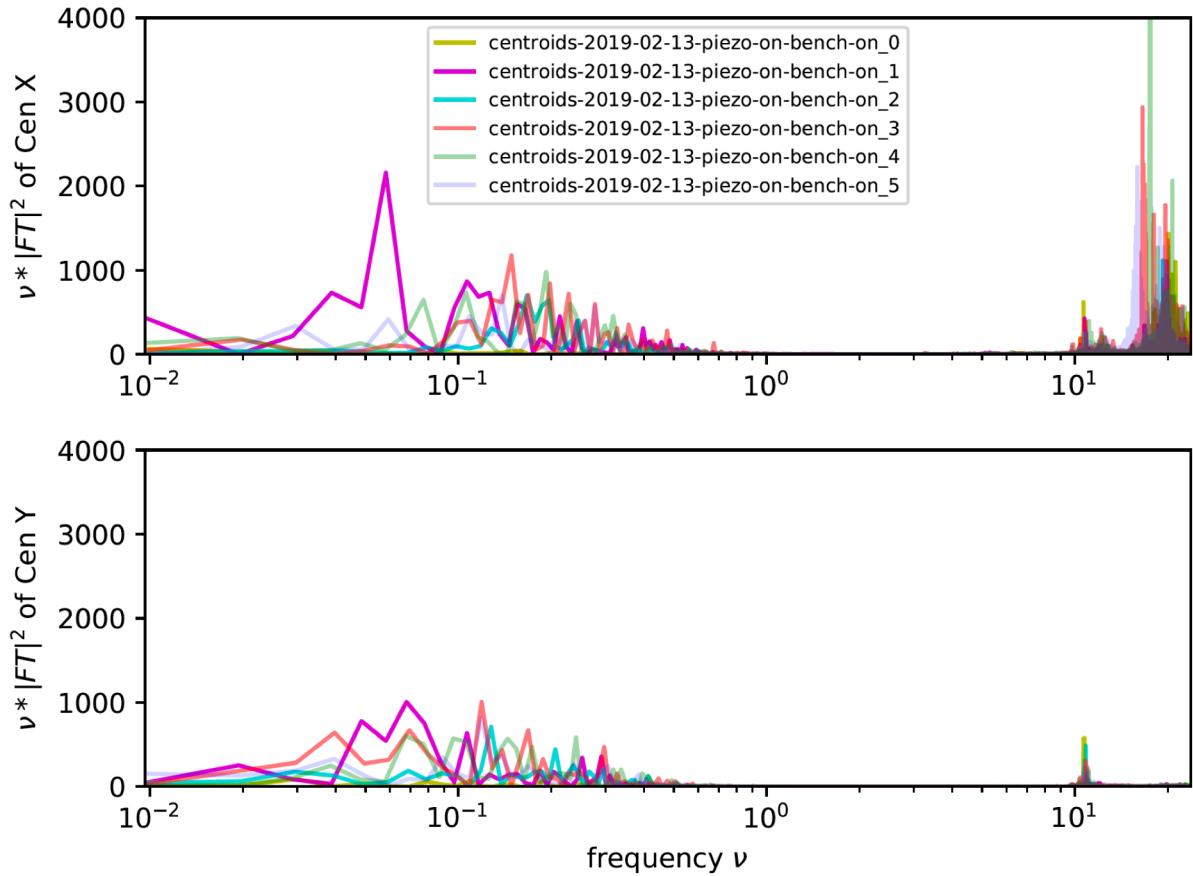
Brighter-fatter effect

Understanding image motion

Centroid measured by the detector (CMOS) with different elements of the testbed switched on and off:



Understanding image motion



Challenges for ongoing and forthcoming surveys

- **Detectors effects**
 - Precise calibration
 - Impact on cosmological observables
- **Data analysis**
 - Photometric redshift
- **Modeling of the observables**
 - Evolution of the universe on small scales (in different models)
 - Speed and accuracy of numerical computations
- **Cosmological analysis**
 - cosmological parameter estimation
 - tension metrics
 - blinding

Take away: weak lensing to probe cosmic acceleration

- Towards high precision measurements
- Weak lensing to constrain modified gravity: beware of IA -- LSST is promising.

State-of-the-art: DES Y1

- Main constraining power on extensions to Λ /wCDM models: modified gravity.
- No evidence for deviations to Λ CDM but tensions to investigate.
- Preparing for DES Y3: more data, more combination of observables, more models!
Work in progress

Back up slides

	DES Y5	LSST
Sky coverage (deg ²)	5000	18000
Number redshift bins	5	10
n_{gal} (/arcmin ²)	10	55
σ_ϵ per bin	0.25	0.2
$\sigma(z)$	$0.05(1+z)$	$0.02(1+z)$

TABLE II. Specifications for DES Y5 and for an LSST-like survey, used in our Fisher analysis.

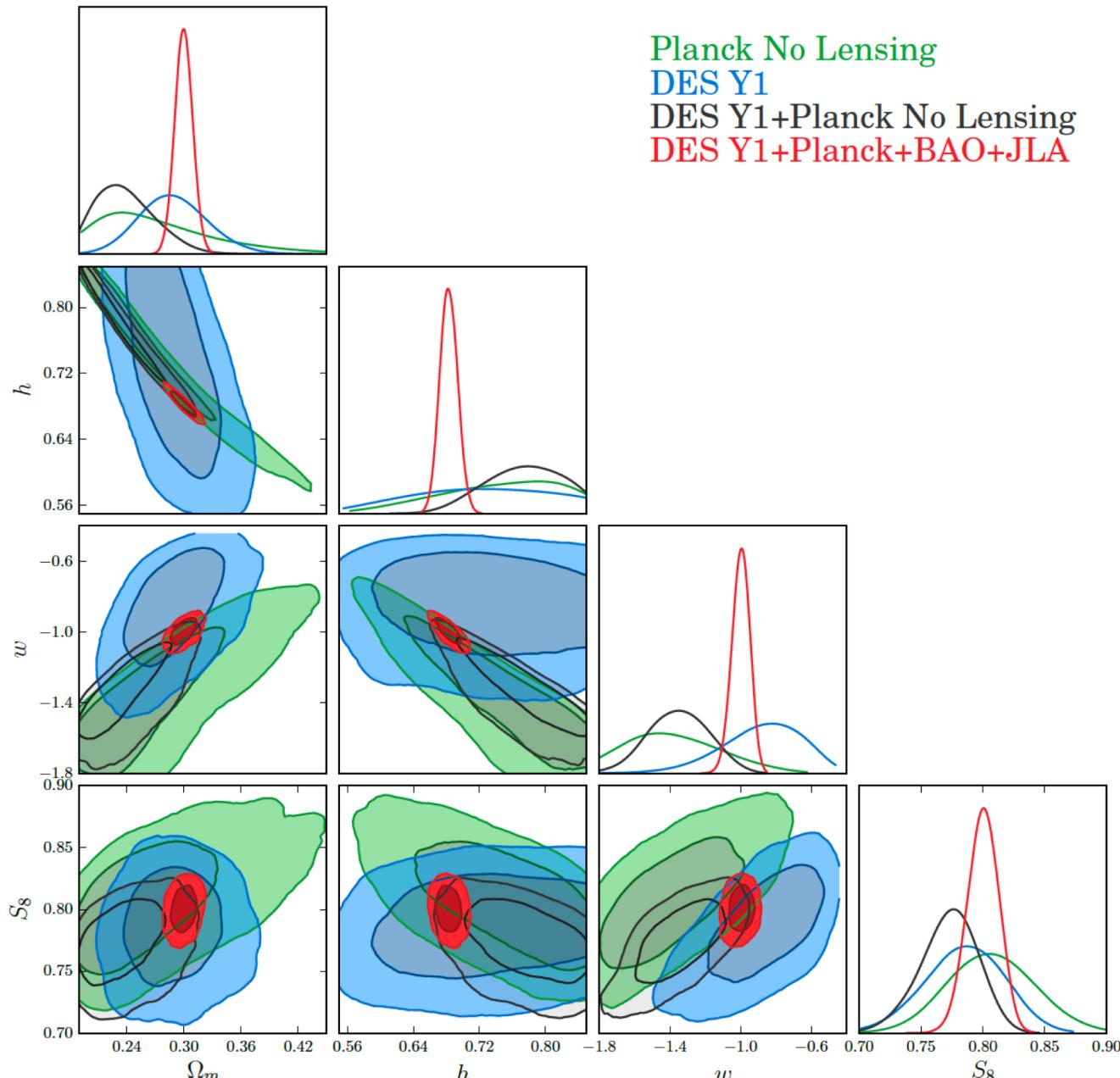


FIG. 14. w CDM constraints from the three combined probes in DES Y1 and Planck with no lensing in the Ω_m - w - S_8 - h subspace. Note the strong degeneracy between h and w from Planck data.